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ORIGINAL ARTICLES.

Tertiary and Quaternary Beds of Tobago, West Indies.

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(PLATES XXIV and XXV.)

TOBAGO, a picturesque island 26 miles long and 7½ miles wide, lies 20 miles north-east of Trinidad and rises to a height of about 1,900 feet. Geographically it is an indirect lateral offshoot of the Northern Range of Trinidad but geologically its structure has distinct and individual characters. The sequence of formations has been described by Mr. E. H. Cunningham Craig[1] and my sketch map is adapted from his map with a few additions, such as the *Arca patricia* bed at Red Point and the outlier of coral rock at Plymouth. I spent about a week on the island and devoted most of the time to work on the later formations.

More than half of Tobago consists of a dark coloured igneous rock which has been called an epidiorite but which is said to pass in places into a coarse dolerite or gabbro. It is quite likely that a detailed examination of the igneous complex would reveal a variety of petrological types. In places for instance near the Botanical Garden at Scarborough it, or the rock into which it has been intruded becomes schistose or quartzose and is veined with chloritic or talcose material. In other places as at High Woods waterfall near Moriah a lighter-coloured dioritic rock is traversed by veins of a dark green material, apparently a lamprophyre or kersantite.

On the shore at Bacolet Point south-east of Scarborough the rock is dark green and takes on a broken up or agglomeratic character.

Further inland north of Government House a compact fine-grained rock enclosing large twinned felspar phenocrysts is quarried for road material.

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[1] Prelim. Report by Government Geologist on Island of Tobago. Trinidad Council Paper, No. 9, 1907.

The northern and much of the western part of Tobago is occupied by the series of schistose rocks into which the igneous complex is presumed to have been intruded. Cunningham Craig indicates on his map felspathic grits, talcose schists, talc-mica schists, quartzose grits, and schistose grits. The schists are well seen around Speyside and opposite the island of Little Tobago and on the track thence across the island to Man of War Bay, where they dip nearly vertically and are much contorted and are green coloured and siliceous with many quartz veins and inclusions. In places they are very suggestive of some of the rocks of the northern range of Trinidad but limestones that form so large a part of that range seem to be absent from Tobago. I saw no trace of fossils in the Tobago schists and the prospect of there being any seemed very remote.

The schist and epidiorite country of Tobago is very hilly and ravined but it sinks down southwards and south-westwards.

The only known occurrence of igneous rock in the Northern Range of Trinidad is a small patch of green epidiorite at Sans Souci Bay near the north-east corner of the island. On account of the similarity of much of the igneous rock of Tobago with that at Sans Souci and the general affinity of the schists of Tobago and Trinidad one may surmise that the schistose beds are of corresponding age, that is to say probably Mesozoic. The absence of fossils from the Tobago schists however precludes any certainty on this point. A suite of fossils, largely sponges, that I found recently at Toco just east of Sans Souci in Trinidad seems to indicate that the whole northern range is formed of Mesozoic rocks. Dr. H. D. Thomas is preparing an account of these sponges and kindly informs me that they seem to be Lower Cretaceous forms rather than Upper Jurassic as I previously supposed. R. A. Liddle[1] considers the Trinidad Northern Range as not older than Silurian nor younger than Devonian.

Tobago may perhaps be looked on as a more stable portion of the earth's crust than Trinidad. I was told that earth tremors are few and feeble in Tobago, whereas in Trinidad they are more frequent and inclined to be severe. The Tertiary beds in Tobago lie almost undisturbed.

THE TERTIARY BEDS.

Tertiary beds occur in patches to the east and west and south-west of Scarborough the Capital. The Tertiaries are very thick in Trinidad but appear to be thin in Tobago though possibly they may thicken to the south-west below the coral rock. At least one bed, that containing *Arca patricia* exposed in Little Rockly Bay just south of Red Point shows very definitely that a shore line existed in south Tobago in Miocene times. Here on the south side of the mass of epidiorite at Red Point a very coarse conglomerate rests on and against the rising irregular edges of the dark green igneous rock. Above the conglomerate come the beds with many specimens of *Arca patricia, Ostrea,* and *Anomia,* the latter often growing on the backs and apices of specimens of *Arca. Vermetus*-like gasteropods are also found attached to the larger pebbles in the conglomerate. The section is as follows :—

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[1] *Geol. of Venezuela and Trinidad,* 1928, 431.

Arca Patricia Bed in Little Rockly Bay.

	Feet.
Soft brown band with flattened concretions; an occasional *Arca patricia*	6
Pebble bed with small *Ostrea*	2
Soft brown bed with large *Ostrea*	3
Hard brown bed with occasional pebbles and many *Ostrea* and *Arca patricia*	2
Layer of small *Ostrea*	1
Bed of large rounded pebbles with *Ostrea* and *Anomia* attached, and *Arca patricia*	2
Bed of smaller rounded pebbles	2
Bed of small *Ostrea*	2
Bed of coarse conglomerate with large and small pebbles, angular and rounded. Many of the pieces agree with the rock immediately below; there are also reddish porphyry, green jaspery rock, white quartz, and green schists the latter resembling rocks now occurring at the north and west sides of the island.	4
Unconformity; very irregular junction.	
Epidiorite; the surface decomposed and veined with green streaks	?

The *Arca patricia* bed seems to be the oldest Tertiary exposed in Tobago. In Rockly Bay or Scarborough Bay north of Red Point the typical Tertiary red or brown nodular clay or Tobago "Crag" as it has been called, full of Balani, is seen for about half a mile. The actual place at the south end of Scarborough Bay where its base should rest on the underlying epidiorite is unfortunately built over so that neither the nature of its base nor its possible relation to the *Arca patricia* bed could be observed. The *Balanus* clay has innumerable small pebbles mixed up with it and was probably also laid down near a shore line. It has a wider extension than, and apparently overlaps, the *Arca patricia* bed which I saw only in one limited exposure just south of Red Point.

Section of Tobago "Crag" along the Southern Part of Rockly Bay, about a mile south-west of Scarborough.

	Ft.	*In.*
Grey and green thinly bedded clays, no fossils	10	–
Brown very well bedded clays, no fossils.	15	–
Irregular junction.		
Brown hardened layer of calcareous clay, *Balanus* fragments		2
Brown clay, nodular at the base, full of *Balanus,* also *Pecten, Anomia, Ostrea, Scalaria,* etc.	5	–
Hard brown nodular clay-ironstone band on the shore; *Fasciolaria, Malea, Conus, Spondylus,* etc.	5	–
Bed of small clayey oolites with branching sponge-like structure	2	–
Soft brown clay with a few *Balanus*	3	–

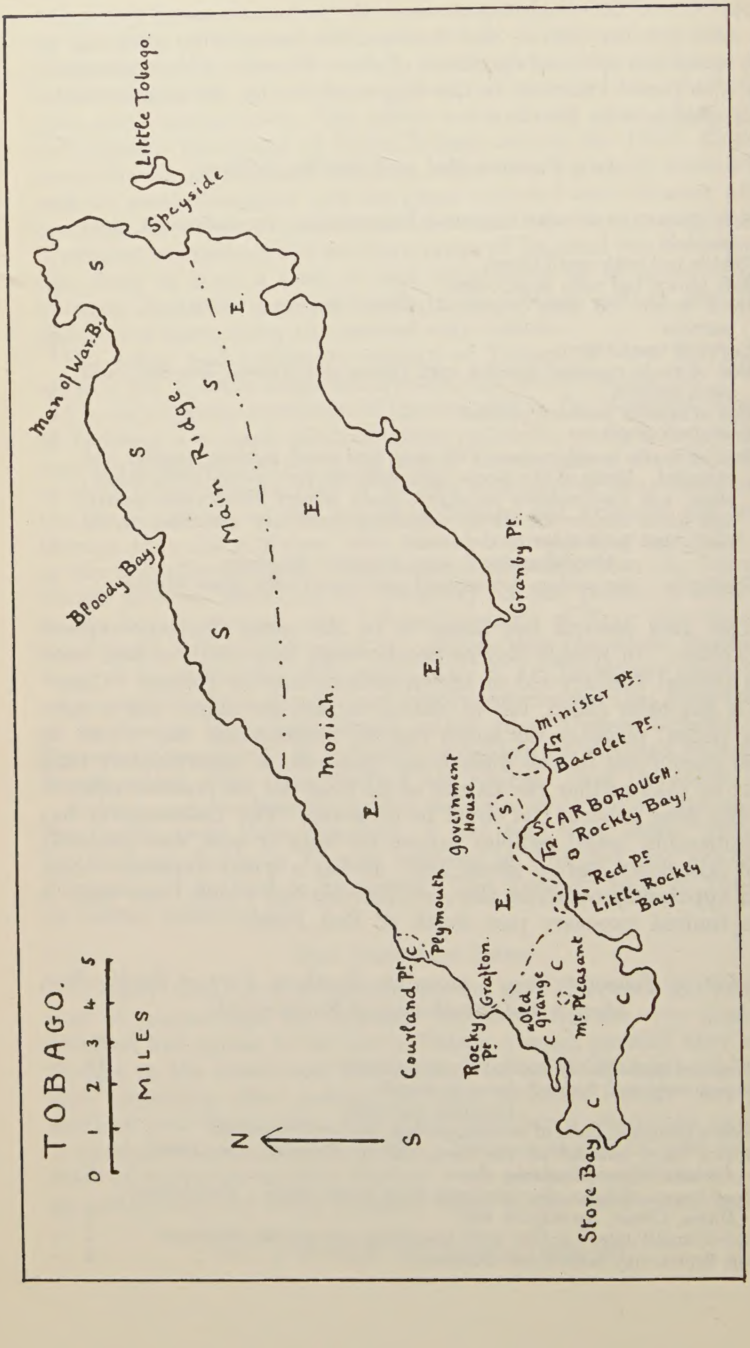

Fig. 1.—Sketch Map of Tobago. SS Schist country. E.E. Epidiorite country, boundary approximate. CC Area covered by Coral Rock. T_1 Exposure of *Arca patricia* bed, S.W. of Red Point. T_2 Tobago Crag or Balanus clays west and east of Scarborough.

Minister Bay East of Scarborough.

One and a half miles east of Scarborough between Bacolet Point and Minister Point the Tertiary clays occupy a depression about ½ mile wide extending inland for nearly 1 mile where up the Sandy River they can be traced in ditches and other exposures. They are not seen on the coast anywhere in the bay ; but on the side of the road from Minister Bay towards Scarborough a section is exposed as follows :—

	Feet.
Brown clay with layers of flattened calcareous nodules. Soft brown clay with occasional Balani and *Ostrea*. Pebbly clay resting on Epidiorite but junction not seen.	15

A good exposure of the *Balanus* beds is seen at the Government Stock Farm nearly two miles west of Scarborough and about half a mile from the coast.

On the south-west coast of the island near Rocky Point sections of brown bedded nodular clays occur here and there below the coral rock but except for a few Balani and Pectens they are very unfossiliferous.

Tertiary clays with Balani and other fossils are also seen at intervals on the roadsides between the east and west coasts from Red Point to Rocky Point.

FOSSILS FROM THE UPPER MIOCENE OF TOBAGO.

All are from the Tobago " crag " and the brown clay-limestone concretions in it, except *Arca patricia*, *Anomia*, and *Vermetus*.

Several other mollusca were collected in the crag but are all poorly preserved, a *Cardium*, *Modiola*-like shell etc. Polyzoa include a *Lunulites* or *Cupularia*-shaped form up to 20 mm. in diameter, but I saw neither corals nor foraminifera. A branching sponge-like or possibly algal structure occurs in a matrix of small argillaceous oolites on the shore in Scarborough Bay.

Balani occur in extraordinary profusion and Mr. T. H. Withers F.G.S. kindly writes me regarding them " there is no doubt that nearly all of them belong to the species *Balanus tintinnabulum*, for I have discovered in some of them the opercular valves. There is, however, a second species, which might be *Balanus amphitrite*, but there is not sufficient material to be sure of the species, although it is quite distinct from *B. tintinnabulum* ".

Conus cf. *furvoides* Gabb. Pl. XXV, Fig, 9.

A slender cone shell, spire with concave sides and about eleven whorls, smooth, sutures sharp and well incised ; anterior end of the shell with several finely incised spiral lines, otherwise the surface is smooth. Length 31 mm.

It resembles *C. furvoides* Gabb which was not illustrated, but

Miss Maury[1] figures it from Cercado de Mao, Dominican Republic. It also recalls *C. limonensis* Olsson[2] from the Gatun stage of Port Limon, Costa Rica.

Ancilla (*Eburna*) sp. Pl. XXV, Fig. 10.

Shell of 5–6 whorls, the spire high, tapering, sides gently rounded smooth, sutures well marked, shallow. The early whorls and the penultimate whorl just above the suture have a shallow canal with three thread-like spiral grooves situated on the hinder part of the canal. The body whorl at the anterior end carries three spiral well marked grooves; the under surface was not seen. Length 42 mm., width of body whorl 22 mm. A mould from which an impression was made.

The shell is rather like the living *Ancilla* or *Eburna glabrata* Linn., from the West Indies but is smaller and has the sutures better defined and less obscured by callosity and the spire less acute. Miss Maury records three species of *Ancilla* from the Trinidad Miocene. *A. lamellata* Guppy; *A. brassica* Maury; and *A. caroniana* Maury; the last one may come nearest to the Tobago cast.

Malea cf. *elliptica* Pilsbry and Johnson. Pl. XXV, Fig. 11.

A cast from the mould of a *Malea* is 40 mm. high and 32 mm. wide and has 17 or 18 concentric rather flattened ridges on the body whorl. Sutures are well sunken and the spire rather high.

It may be the same as *M. elliptica* Pilsbry and Johnson figured by Olsson[3] from the Gatun stage of Estrella River, Costa Rica, a species which has 22 closely spaced spiral bands said to be ribbon-like but which attains a height of 60–80 mm. It is less like *M. camura* Guppy the body whorl being more bulbous and more inflated anteriorly, the spire broader and higher and more platformed, and the shell apparently thinner.

Natica cf. *catena* Da Costa. Pl. XXV, Fig. 5.

One small free specimen 8 mm. wide and 8 mm. high and another 20 mm. wide and 20 mm. high are not unlike specimens of *N. catena* Da Costa of the English Red Crag. The shell is rather thick and whorls rounded increasing rapidly in size and the last whorl rather inflated, spire somewhat pointed and sutures well sunken, umbilicus small with a callosity which has been broken away. Perhaps the shell of the Tobago specimens is thicker and the sutures less sunken than in *N. catena.*

Scalaria sp. Pl. XXV, Fig. 4.

Part of the last whorl of a small *Scalaria*, 6 mm. wide and 5 mm. high has about 12 ribs to the whorl; the ribs are strong and prominent, the edges turned backwards but not sharp, the aperture slightly oval with a strong smooth rim.

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[1] *Bull. Amer. Pal.*, 1917, No. 29, p. 42. Pl. 7, figs. 1 and 2.
[2] *Bull. Amer. Pal.*, 1922, vol. v, p. 47. Pl. 3, figs. 7 and 8.
[3] *Bull. Amer. Pal.*, No. 39, 1922, p. 139. Pl. 12, fig. 2.

Vermetus sp.

An elongated mass 30 mm. long of irregularly twisted and convoluted *Vermetus* attached to larger pebbles in the *Arca patricia* bed. The sculpture of the shell is destroyed but is resembles a living " *Vermetus* " that occurs very firmly fixed to rocks between tide marks in the West Indies.

Fasciolaria (*Xancus*) *semistriata.* G.B.Sow. Pl. XXV, Fig. 8.
Quart. Journ. Geol. Soc., vi, 1849, p. 49.

Shell thick, of about 8 whorls the earlier 4 are tuberculated or polygonal, the last 3 whorls are bulbous the last one becoming well inflated and smooth with faint growth lines. Suture rather irregular and acutely channelled with a sharp upstanding carinated margin. the inner lip with three rather prominent columellar folds. One specimen from the Tobago crag, the apex and anterior end damaged, length 145 mm., width 86 mm.

This species was not figured in 1849. Miss Maury says that specimens from the type locality in the Dominican Republic are only 95 × 40 mm. in size. From the Springvale Miocene of Trinidad she describes and figures *Xancus trinitatis*[1] Maury ; and *X. praeovideus* Maury ; the first being a large species up to 300 × 100 mm. in size. The Tobago specimen rather resembles the latter but has a shorter spire and is more stumpy.

Guppy says that Springvale specimens of *Fasciolaria semistriata* exceed 8 inches in length and 3½–5 inches in diameter and vary with age and growth.

The living *Turbinella* or *Xancus ovoidea* Kiener from Brazil is not greatly different but is smaller and more provided with spiral riblets.

Fasciolaria sp.

A cast of a shell 110 mm. long and 74 mm. in diameter seems to belong to this genus and recalls in shape the recent *F. tulipa* but is broader in the body whorl.

Fissurella (*Glyphis, Diodora*) sp.

Parts of a mould from which impressions were made show a Fissurellid about 10 mm. long and 5 mm. high. It has radiating ribs some of them primary and others intercalated but all of about equal height, crossed by growth lines giving a sharp but rather irregular reticulation. The apical aperture seems to have been forwardly situated and relatively large.

It is not unlike *Diodora alternata henekeni* Maury ; as figured by Woodring[2] but is more conical. It also recalls the living West

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[1] *Bull. Amer. Pal.*, vol. 10, 1925, No. 42, p. 208. Pl. 39, fig. 1.

[2] Bowden mollusks. Carnegie Inst. Publ., 1928, part ii, pl. 39, fig. 16.

Indian *Glyphis alternata* Say, but in that form the radiating ribs are alternately prominent and low.

Arca (*Scapharca*) *patricia.* G.B.Sow. Pl. XXV, Figs. 12 and 13.
Quart. Journ. Geol. Soc., vol. vi, 1849, p. 52.

Tobago specimens of *A. patricia* vary considerably in length and height and size of the hinge area. One specimen is 116 mm. long and 94 mm. high and has an area 29 mm. high ; other specimens are relatively shorter and broader, one is 97 mm. long and the same high and has a very large triangular area 36 mm. high.

It is common in pebbly beds on the south side of Red Point, sometimes fixed in the very hard green rock or the valves weathered out in soft clay.

The external ribbing is rather like that of the recent Panama species *Arca* (*Senilia*) *grandis* Brod. and Sow., but both this and the large living West African estuarine *Arca* (*Senilia*) *senilis* Linn., the two largest living Arcas, have the shell relatively thicker and the area smaller and more constant in size. The higher conical area of *A. senilis* suggests that of *A. patricia* but in the fossil the plate supporting the line of hinge teeth is always thinner than in the two living species.

Miss Maury says that Professor Harris from field observations in Trinidad found the *Arca patricia* horizon far above the Springvale Miocene and places it in the uppermost Miocene. Guppy records *A. patricia* from Yabalito, Urumaco, Venezuela as well as from Haiti, Trinidad, and Tobago.

According to Woodring *Arca patricia* has not yet been recorded from Pliocene deposits. Referring to its occurrence in Colombia [1] he remarks " the giant *Senilia* that is remarkably like the recent Panamic *S. grandis* Brod. and Sow. occurs throughout the Miocene section ". The Tobago specimens are not at all closely similar to *A. grandis.*

Pectunculus (*Glycimeris*) cf. *acuticostatus* Carrick Moore. Pl. XXV, Figs. 6 and 7.
Quart. Journ. Geol. Soc., vi, 1849 (1850), p. 53. Pl. x. fig. 13.

Two valves of a small ribbed *Pectunculus* 20 mm. wide and 19 mm. high have about 26 rounded or bluntly angulated ribs and may be identical with *P. acuticostatus.*

The ribs are rather irregular, the central ribs are rather broad and have wider interspaces and some of them are flanked by finely cut grooves, otherwise the shell is not easily distinguishable in size or shape from the recent *P. pectinatus* Gmel. The recent form seems to have more regular ribs and is recorded from the Pliocene ; another allied recent species, *P. undatus* Linn. is recorded from the Miocene.

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[1] *Miocene Mollusks from Bowden*, part ii, 1928, 79.

Pecten cf. *maturensis* Maury. Pl. XXV, Fig. 3.

Left or convex valve rather inflated especially near the beak, right valve nearly flat, auricles relatively large, the anterior ear of the right valve well cut out below. 16 or 17 plain well rounded raised ribs diverge from the umbo and widen gradually, interspaces are plain and rather wider than the ribs and are marked by fine sharp growth lines which become obsolete on the ribs. Anterior and posterior ears carry 8 or 9 radial ribs and are crossed by fine growth lines especially towards the margin.

As only a few disconnected valves were found and it is not certain if these belong together it does not seem advisable to identify very definitely these Pectens. The convex valve may be related to *P.* (*Plagioctenium*) *andersoni* Arnold and *P. raymondi* Clark or variety *P. raymondi brionianus*[1] of the Californian Miocene but the ears are relatively larger and the ribs fewer than in the last species.

They seem to resemble more closely *P. maturensis*[2] Maury from the Trinidad Miocene in general features, shape and size of the ears. Another related species may be *P. cercadica*[3] Maury from the Miocene of the Dominican Republic which has 16 rounded radial ribs but with narrower interspaces.

Spondylus cf. *bostrychites* Guppy.

A double valved specimen with the shell much damaged and a piece of another thick shelled specimen seem to belong to some form very near *S. bostrychites* Guppy or possibly to *S. chiriquensis* Olsson. The larger ribs bear spine bases at intervals and between them are 3–6 finer ribs.

Anomia sp. Pl. XXV, Fig. 2.

Shell thin, wider than high, inequilateral, upper or left valve moderately inflated, in one specimen considerably inflated near the beak; the beak is inconspicuous slightly twisted posteriorly, the hinge margin thickened and rather strongly incurved. Growth lines are very irregular and decoration consists of several low indistinct wavy radial ribs. The left valve is not clearly seen.

Generally attached to the back or beak of *Arca patricia.* It is not unlike *A. vaquerosensis*[4] Loel and Corey from the L. Miocene, Vaqueros formation of California but that species has broader and more distinct radial ribs than the Tobago fossil.

Ostrea sp. Pl. XXV, Fig. 1.

A large Oyster occurs in the *Balanus* bed; three fixed valves were collected, the largest 170 mm. long, 110 mm. wide, and 80 mm. deep, the other two smaller; the upper valve was not seen. The beaks are tapering and triangular and directed anteriorly, the area concave, the valve is very thick and strongly excavated the sides turned upwards. The exterior of the large specimen is rounded and thickened or humped near the umbonal region and has scarcely any trace of radial folds but has irregular growth lines and foliation.

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[1] *Univ. Calif. Publ.*, 1922, vol. 13, No. 5, p. 148. Pl. 1, figs. 4 and 5.

[2] *Bull. Amer. Pal.*, 1925, vol. x, p. 89. Pl. 14, figs. 3 and 4.

[3] *Bull. Amer. Pal.*, 1917, vol. v, p. 189. Pl. 34, fig. 11.

[4] *Univ. Calif. Publ.*, 1932, vol. 22, p. 203. Pl. 33, figs. 1–4.

It seems to agree with the description of specimens and figures of *Ostrea puelchana* D'Orb as recorded by Maury[1] from Trinidad. She remarks that it occurs in the Middle and Upper Miocene, Pliocene, Pleistocene, and Recent.

COMPARISON WITH THE TRINIDAD TERTIARIES.

The dip of the Tertiary beds in Tobago is slight or insignificant, and it is evident that they represent only the higher part of the thick Tertiaries of Trinidad. In Trinidad *Arca patricia* characterizes the Caroni beds north of the Central range. In the Manzanilla section on the east coast it is said to extend down to the horizon of the Springvale beds, that is to say approximately Tortonian. It generally occurs however in the Upper Caroni beds (= Sarmatian or Upper Miocene). Woodring regards the Springvale beds as Pontian or Sarmatian. The Caroni beds in Trinidad are, as Dr. E. Lehner tells me, definitely folded but not to any great degree.

From the *Balanus* bed or Tobago "crag" the only fossil that seems much use for correlation is *Fasciolaria semistriata* which occurs in the highest Miocene in Trinidad.

Balani so profuse in Tobago are rare in Trinidad though they occur in the Springvale beds.

WHITE MARLS. PLIOCENE (?).

At Old Grange 4½ miles west of Scarborough a disused windmill stands on an irregular hill or spur about 120 feet high from which a fine view of the west coast is seen. The hill is capped by a white well-bedded chalky-looking deposit which dips slightly to the south-east and stands well above the surrounding coral rock. Similar material occurs at other places but its precise relation to the coral rock or to the brown Tertiary beds was not clear to me. The section at Old Grange is as follows :—

	Feet.
White friable marly material made up of comminuted shell fragments, containing large and small Oysters, Balani, etc. but very few if any corals. Near the base which is very irregular many *Lithothamnion* nodules and pebbles of rotted epidiorite occur. . .	15–20
Unconformity	
Decomposed igneous rock	?

Fossils collected at Old Grange include :

Ostrea haitensis G.B. Sow. A large oyster consisting of two senile valves grown back to back, 142 mm. long and 127 mm. wide. Not much of the outer surface is visible but they seem to belong to this species.

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[1] *Bull. Amer. Pal.*, 1925, *Bull.* 42, p. 79.

Ostrea frons or *O.* (*Lopha*) *guppyi* Woodring. Two upper valves *Balanus* sp.

Amphistegina sp. A few scattered specimens.

Lithothamnion sp. Nodules about 30 mm. in diameter with corrugated or knobby surface.

THE CORAL ROCK OF TOBAGO.

Coral rock covers the southerly, flatter part of Tobago south of a line passing from south of Red Point on the east to Rocky Point on the west coast. An outlier of it occurs at Courland Point and Plymouth some distance north-west of Rocky Point. It rises from the coast in flat terraces but except when viewed from a distance the terraced profile is not very apparent. I do not think the coral rock on Tobago rises to more than 120 feet at the highest, nor does it seem to have covered very much more of the island than the area it now occupies. Its northern edge may be somewhat denuded and towards the extreme south coast near Friendship it has been ravined by small watercourses.

At Mount Pleasant 158 feet high the coral rock surrounds an emergent mass of epidiorite on which a church stands and knobs of the underlying rock also project at a few other places. The coral rock slopes gently down to the south and south-east coasts but along the south-west coast the sea tends to undercut it forming a line of cliffs 15 or 20 feet high such as those that are picturesquely displayed at Store Bay. At its northern boundary where it passes up on to the rising slopes of epidiorite it becomes thin but it may thicken somewhat southwards. Near its northerly limit on the west coast at Grafton it overlaps the Tertiary clays and rests on the epidiorite; here a good roadside section shows about 20 feet of old coral rock with large dissolved coral masses and a few fragmentary *Ostrea frons* at the base resting on a surface of decomposed igneous rock.

The Tobago coral rock looks old and compact and sometimes occurs in thin layers, the corals are rotted and dissolved and there are scarcely any recognizable mollusca. An outlying area of coral rock occurs around Plymouth the one-time capital of Tobago, and here in the cliffs just to the south of Plymouth in Great Courland Bay I succeeded in finding a small series of fairly well preserved mollusca, some of them large and conspicuous species. The section is as follows :—

Coral Rock on Coast south of Plymouth.

	Feet.
Old coral rock with large coral masses very much rotted, higher up are branching corals; a bed with Lithothamnion nodules occurs towards the base, and yields mollusca often broken, with the shell structure strongly recrystallized	25
Unconformity.	
Brown clay with rounded pebbles of various sizes; quartz, and igneous rocks, the latter often with large twinned felspars. This seems to be either the Tertiary bed or debris derived from it . . .	5

TOBAGO CORAL ROCK FOSSILS.

All are from the base of the coral rock outlier at Plymouth.

Xancus (*Turbinella*) *scolymus* Gmel ; variety. Pl. XXV, Fig. 14.

Two large specimens 185 mm. long and 93 mm. wide, resembling a recent but smaller specimen ; the fossil has five nodes on a whorl while the recent example has six. It attains a large size on the Brazilian coast.

Cynodonta muricata Born (= *pugillaris* Lam.)

Cypraea exanthema Linn. Two broken specimens.

Cypraea near *spurca.* Linn. One specimen.

Marginella interruptolineata Megerle. One specimen 12 mm. long.

Oliva, a fragment probably of *O. reticulata* Lam.

Conus testudinarius Mart.

Conus mus, Hwass.

Conus sp.

Coralliophila near *galea* Chem. or *abbreviata* Lam. A small specimen 14 mm. in diameter probably the same as a form common in the Barbados coral rock.

Natica probably *N. canrena* Linn.

Astralium (*Lithopoma*) *imbricata* Gmel. Specimens have heavy and broad ribs which are interrupted by a wide groove a little above the suture, more like the ornamentation on the Panama analogue *A.* (*Uvanilla*) *unguis* Wood than on the common living West Indian form *A. imbricata.*

Ostrea frons Linn. Small specimens.

Pecten ornatus Lam. Fragments.

CONTRAST WITH THE BARBADOS CORAL ROCK.

Although 150 miles distance and more than 800 fathoms depth of sea separates Barbados from Tobago the partial covering of coral rock on Tobago forms a sort of link with Barbados, but on the latter island it has been raised to the much greater altitude of over 1,000 feet and the terraces are much more pronounced. None of the profusion of fossil mollusca one meets with on Barbados occurs on Tobago. I could not find on Tobago the *Amphisteginae* that are so conspicuous at the base of the Barbados coral rock especially at high levels. The mollusca at the base of the Tobago coral rock are forms of recent aspect whereas in Barbados the coral rock seems to go back in places to the Pliocene. Among other fossils I collected this year at the base of the coral rock at Whitehaven, Barbados, is a species of *Haliotis* a genus not known living in the Caribbean area except a very rare deep water form off Florida. This, together with a *Meiocardia* and some Terebratulids seem to put the commencement of the Barbados coral rock back to pre-Pleistocene times. In spite of its old look I should consider the Tobago coral rock to be a formation of later commencement and lesser duration than that of Barbados.

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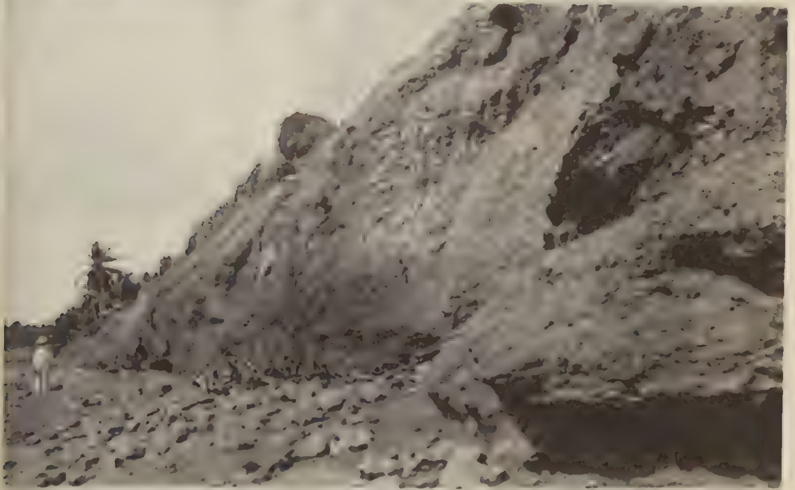
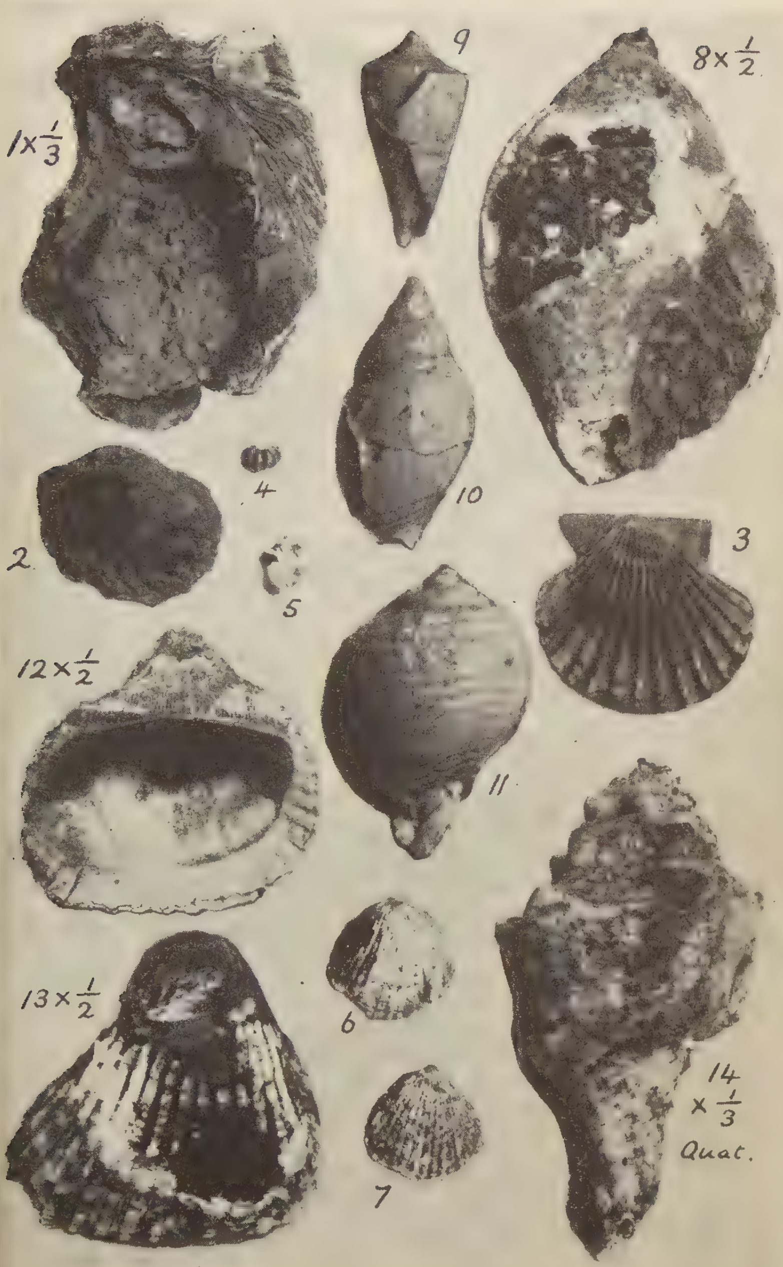


C. T. T. photo.

Views of Tobago. Miocene Beds and Coral Rock.

Plate XXV.



C. T. T. photo.

Miocene and One Quaternary Fossil from Tobago.

EXPLANATION OF PLATES XXIV AND XXV.

PLATE XXIV.

FIG.

1.—The *Arca patricia* bed with conglomerate at its base resting on and against the epidiorite in Little Rockly Bay, south-west of Red Point.

2.—The *Balanus* clays or Tobago "Crag" on the shore at the south-west side of Rockly or Scarborough Bay.

3.—Store Bay, south-west Tobago, cliffs of coral rock partly undercut by the sea.

PLATE XXV.

(Natural size unless otherwise stated.)

FIG.

1.—*Ostrea* sp.; a large fixed valve, interior view. Upper Miocene, *Balanus* bed, Scarborough Bay. Rather over one-third natural size.

2.—*Anomia* sp.; upper or left valve. Same locality.

3.—*Pecten* cf. *maturensis* Maury; left valve. Same locality.

4.—*Scalaria* sp.; portion of a last whorl. Same locality.

5.—*Natica* cf. *catena* Da Costa. Same locality.

6.—*Pectunculus* cf. *acuticostatus* Moore; right valve. Same locality.

7.—Ditto, another specimen; left valve. Same locality.

8.—*Fasciolaria* (*Xancus*) *semistriata* G.B. Sow.; same locality, nodular bed below the *Balanus* bed. Rather under one-half natural size

9.—*Conus* cf. *furvoides* Gabb; gelatine cast from a mould. Same locality and bed.

10.—*Ancilla* (*Eburna*) sp. Gelatine cast. Same locality and bed.

11.—*Malea* cf. *elliptica* Pilsbry and Johnson; gelatine cast. Same locality and bed.

12.—*Arca* (*Scapharca* or *Senilia*) *patricia* G.B. Sow.; left valve. Above the conglomerate bed in Little Rockly Bay. Rather under one-half natural size.

13.—Ditto; right valve of the same specimen with an *Anomia* growing on the outside of the beak.

14.—*Turbinella* (*Xancus*) *scolymus* Gmel; base of the Coral Rock at Plymouth. Rather over one-third natural size.

The Origin of Earthquakes as illustrated by their Periodicity.

By CHARLES DAVISON, Sc.D., F.G.S.

SOME recent studies on the periodicity of earthquakes have thrown light on their origin and especially on that of their attendant after-shocks. The periods that are of most service for this purpose are the solar periods of one year and one day, the lunar periods of 29·6 and 14·8 days, and the period of 42 minutes due to the throbbing of the earth in consequence of the crustal displacement that gives rise to the earthquake.[1] As a rule, the maximum epoch of the annual period falls either in midwinter or in midsummer, that of the diurnal period about midnight or noon, that of the period of 29·6 days close to the times of either new and full moon, that of the period of 14·8 days at or about the times of new and full moon or of first and last quarter, and that of the 42 minute period either with the return movements after their passage to the antipodes and back or half-way between these returns.

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[1] (1) "The Annual Periodicity of Earthquakes," *Amer. Seis. Soc. Bull.*, xviii, 1928, 246–266; (2) "The Diurnal Periodicity of Earthquakes," *Journ. of Geol.*, xlii, 1934, 449–468; (3) "The Lunar Periodicities of Earthquakes," *Phil. Mag.*, xvii, 1934, 737–752; (4) "The 42 minute Period in the Frequency of the After-shocks of Earthquakes," *Amer. Seis. Soc. Bull.*, xxiii, 1933, 57–79.

An important point to notice is that, in the shorter periods, the epochs are subject to complete reversal. This reversal does not imply that the cause producing the periodic variation acts at times in precisely opposite directions, but rather that, in each period, the direction of action is constant while the crust-movements giving rise to the earthquakes are sometimes upwards and at other times downwards. For instance, if a great earthquake were due to a sudden uplift of the crust, many, if not most, of the early after-shocks might be caused by a settling down of the displaced mass. The maximum-epoch of a period may thus throw light on the directions of crustal movements in various parts of the earth.

As a rule, the evidence reveals the occurrence of changes in the direction of the movement rather than the actual directions. It seems probable that, for earthquakes on land, the annual and diurnal periods are closely connected with the variations of atmospheric pressure. These have maxima, as a rule, in mid-winter and shortly after midnight. Thus, if, in any region, the epoch of the annual period occurs in midwinter or that of the diurnal period about midnight, the earthquakes would be due to depressions of the crust; but, if in midsummer or about noon, to elevations. It is significant that midwinter and midnight maxima on the one hand, and the midsummer and noon maxima on the other, should be frequently associated, but the relation is by no means universal.

Though it is confined to the after-shocks of earthquakes, the evidence of the 42 minute period is less uncertain, for there can be little doubt that the period is due to the throbbing of the earth after the great initial displacement. The time taken by an earthquake-wave to travel from a focus near the surface to the antipodes and back is almost exactly 42 minutes. As the crust within and near the focus remains for a long time in a sensitive condition, the return pulsations should, and do, affect the frequency of the after-shocks. If these shocks are due mainly to a continued exertion of the forces that gave rise to the parent earthquake, then the maximum-epochs of the 42 minute period should occur at intervals of 42 minutes after the great earthquake. On the other hand, if most of the after-shocks are due to movements in the opposite direction, such as those caused by the settling of an uplifted crust, the maximum-epoch of the period should fall about 21 minutes after the return-movements reach the focal region. The maximum-epoch of the period, which usually falls at one of these times, thus throws light on the directions, or, at any rate, the changes of direction, of the movements that give rise to the after-shocks.

We learn most perhaps as to the actual directions of movement from the lunar periods of 29·6 and 14·8 days. If the maximum-epoch of the former occurs at new moon, it is because of the combined attraction of the sun and moon, and this implies that the crustal movement is one of upheaval. On the other hand, if the epoch occurs at full moon, the inference would be that the movement of the crust is one of depression. Similarly, the crust-displacement would be one of elevation or depression according as the epochs of the 14·8 day period coincide with new and full moon or with the first and last quarters.

Professor H. H. Turner edited a valuable catalogue of earthquakes for the years 1918–1924.[1] During these seven years, 2,564 earthquakes were recorded, most of them at several, many of them at a large number of, observatories. Of the total number of earthquakes, 1,576, or 61 per cent, had origins beneath the sea; of the great earthquakes, that were registered at stations more than 80° from the origin, 70 per cent had such origins; and, of the minor earthquakes, registered at less than 80°, 59 per cent. In all three classes of submarine earthquakes, the epochs of the lunar period of 14·8 days coincided with first and last quarters; whereas, for the earthquakes occurring beneath the land, the epochs fell at or near new and full moon. Thus, for the strong earthquakes recorded in this catalogue, the crust-movement was mainly upwards on land and downwards beneath the ocean.

A similar result follows for the earthquakes of Japan. Professor J. Milne compiled a great catalogue of 8,331 earthquakes during the years 1885–1892.[2] Of these, about 30 per cent originated beneath the sea, the epicentres lying from 5 to 40, and usually at 10, miles from the coast. For the submarine earthquakes, the maximum-epoch of the 29·6 day period occurred at full moon, and the epochs of the 14·8 day period at first and last quarters. For the earthquakes with origins below land, the epochs were reversed, falling at new moon for the 29·6 day period and at new and full moon for the 14·8 day period. Again, from Professor Omori's list of the stronger Japanese earthquakes of the years 1902–7,[3] we find that the epochs of the 14·8 day period occurred at first and last quarters for the earthquakes with origins beneath the sea, and at new and full moon for those with origins below the land or narrow inlets. Thus, in Japan, with weak as well as with strong earthquakes, the crust-movements were mainly downwards beneath the sea and upwards below the land.

In addition to the exhaustive catalogue of Japanese earthquakes, we are indebted to Professor Milne for a list of destructive earthquakes from the beginning of the Christian era to the end of the year

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[1] *Rep. Brit. Ass.*, 1928, 241–304.

[2] *Japan Seis. Journ.*, iv, 1895, 1–367.

[3] *Imp. Earthq. Inv. Com. Bull.*, ii, 1908, 58–88.

1899.[1] To indicate their intensity, Milne used a scale of three degrees. Earthquakes of the first degree were strong enough to crack walls or to throw down chimneys or old houses. Those of the second degree unroofed or shattered buildings, and threw some to the ground. By earthquakes of the third degree, whole towns were destroyed and districts devastated. As the numbers of the two higher degrees are comparatively small, they are here grouped together, as earthquakes that would be unlikely to escape record.

Taking, first, the earthquakes of these two degrees, we find that the maximum epoch of the annual period falls in the summer months of either hemisphere, the average of all the epochs being the end of July in the northern hemisphere and the middle of February in the southern. Whether we consider large regions like the two hemispheres or small ones like Italy or Japan, the epoch for earthquakes of intensity 1 is invariably reversed, the average being the middle of January for the northern hemisphere and the middle of July for the southern. The two classes of earthquakes are thus due to movements in different directions, the great destructive earthquakes probably to uplifts and the semi-destructive earthquakes to depressions.

The latter are, indeed, merely the limiting case of the earthquakes that visit every country. In continental regions, the average epoch of the annual period for ordinary earthquakes falls at the end of January in the northern hemisphere and in the middle of August in the southern. In large insular and peninsular districts, the annual period is but slightly marked. In Japan, on the whole, its epoch occurs at the end of May ; in Italy, at the end of June. In small island groups, it is more distinctly marked. This is also the case in small sub-regions of the larger districts, and in them the epochs are often reversed. For instance, in the north-east of Japan, where the earthquakes are chiefly of submarine origin, the epoch occurs from May to July ; in other parts, most frequently in December or January. It is, of course, to this reversal of epoch in different parts that the period for the whole country is so inconspicuous.

It is remarkable, however, that while, for ordinary earthquakes, the epochs for continental regions and their fringing districts are reversed, for great destructive earthquakes the epochs are the same in both. This seems to point to some fundamental difference in the origin of the earthquakes. The difference is probably connected with the focal depth of the earthquakes, the ordinary shocks being mostly of superficial origin, the great earthquakes resulting as a rule from deeply-seated movements. In the ordinary shocks, the crust-movements are usually downwards ; in the destructive shocks, chiefly upwards.

It is, however, with regard to the origin of after-shocks, rather than of ordinary earthquakes, that we learn most from the seismic periods, the lunar periods contributing least, as they require long intervals for their detection. The 14·8 day period has its maximum epochs with new and full moon in the after-shocks of the Calabrian earthquake of 1783, the Kumamoto earthquake of 1889, the Mino-Owari earthquake of 1891, the Assam earthquake of 1897, and the Kwanto earthquake of 1923; that is, after some of the greatest of known earthquakes, the early movements on the whole were upwards. The same period has its maximum epochs with first and last quarters, implying a general movement downwards, in the after-shocks of such earthquakes as those of Andalusia in 1884, Zante in 1893, Hokkaido in 1894, Kangra in 1895, California in 1906, Messina in 1908, Marsica in 1915, and Tango in 1927.

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[1] *Rep. Brit. Ass.*, 1911, 649–740.

One of the most useful periods from this point of view is the diurnal. In ordinary earthquakes, the maximum occurs about noon, but, in after-shocks, is at once transferred to midnight, the average of twenty epochs being exactly 12 p.m. The duration of the reversed epoch is variable. It may be only about a week, as in the Tazima earthquake of 1925 and the Tango earthquake of 1927, or it may be as much as a year or more, as in the Mino-Owari earthquake of 1891 and the Messina earthquake of 1908, or even about two years, as in the Hokkaido earthquake of 1894. But, whatever the duration of the reversal may be, the epoch returns somewhat rapidly to its normal state, the average epoch after return being within a few minutes of noon. Thus, if, as is usually the case, the crustal movement in a great earthquake is a sudden uplift, then the majority of the early after-shocks are due to downward slips. After an interval that ranges from a week to two years, the initial forces reassert themselves, and subsequent shocks—they can hardly be called after-shocks—are caused by further uplifts of the crust.

The preceding paragraph refers to the movements as a whole. Even within the time mentioned, however, there may be several or many reversals in the direction of motion. For instance, we possess two records of the after-shocks at Tokyo of the great Kwanto earthquake of 1st September, 1923, one of the shocks that were perceptible in the capital from 1st September to 1st October, the other of all after-shocks recorded in it until the following 31st January.[1] Deducting the number of perceptible shocks during any interval from the total number, we obtain the number of shocks imperceptible in Tokyo. The following are the epochs for three nearly equal intervals :—

		Perceptible shocks.	*Imperceptible shocks.*
September	2–10 .	11 p.m.	3 p.m.
,,	11–20 .	11½ p.m.	12 noon
,,	21–30 .	12 noon	12 midn.

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[1] A. Imamura and K. Hasegawa, *Imp. Earthq. Inv. Com. Bull.*, xi, 1928, 64–92; T. Yasuda, *Imp. Earthq. Inc. Com. Publ.* (Jap.), No. 100 A, 1925, 261–310.

Thus, in all three intervals, the periods were practically opposed; also, the stronger shocks from 2nd to 20th September were on the whole due to subsidences and from 21st to 30th September to uplifts, whereas the weaker shocks from 2nd to 20th September were caused by uplifts, and from 21st to 30th September by subsidences.

During each interval there must have been reversals in the direction of motion. From the lists of after-shocks, it is evident that the perceptible shocks occurred in groups. During the 29 days (2nd to 30th September) there may have been sixteen intervals during which the perceptible shocks were predominant, and fifteen intervals in which the shocks were mainly imperceptible. It is difficult, however, to define the limits of the intervals, as perceptible shocks might be caused by movements in either direction.

The 42 minute period, on account of its brevity, illustrates more than any other period the rapid changes of direction in the crustal movements to which after-shocks are due. At first, the maximum epoch usually coincides more or less nearly with the return movements or falls halfway between them. To the former class belong the Hokkaido earthquake of 1894, the Calabrian earthquake of 1905, the Kingston earthquake of 1907, the Mexican earthquake of 1912, the Tokyo earthquake of 1921, the Kwanto earthquake of 2nd September, 1923, the Tazima earthquake of 1925, the Murchison earthquake of 1929, and the Hawke's Bay earthquake of 1931. To the latter class belong the Hawaiian earthquake of 1868, the Riviera earthquake of 1887, the Mino-Owari earthquake of 1891, both the Zante earthquakes of 1893, both the Locris earthquakes of 1894, the Sanriku earthquake of 1896, the Kangra earthquake of 1905, the California earthquake of 1906, the Marsica earthquake of 1915, the Fivizzano earthquake of 1920, the Kwanto earthquake of 1st September, 1923, and the Tango earthquake of 1927. On the whole, then, it would seem that the greatest world-shaking earthquakes belong to the second class. In all of these the movements that produced the early after-shocks were in the opposite direction to those that gave rise to the principal earthquakes.

In the earthquakes of both classes, a reversal of epoch usually occurs after a brief interval. The duration of the interval cannot be measured with precision, but it was about 6 hours in the Marsica earthquake of 1915; about 12 hours in the Murchison earthquake of 1929; about 1 day in the Mino-Owari earthquake of 1891 and the Kwanto earthquake of 1st September, 1923; about 2 days in the Hawaiian earthquake of 1868; about 3 days in the Hawke's Bay earthquake of 1931; about 5 days in the Riviera earthquake of 1887, the Hokkaido earthquake of 1894, the Locris earthquake of 27th April, 1894, the Assam earthquake of 1897, the Calabrian earthquake of 1905, the Kingston earthquake of 1907, and the Kwanto earthquake of 2nd September, 1923; about 6 days in the Tazima earthquake of 1925; and about 14 days in the Tango earthquake of 1927.

After some great earthquakes more than one reversal of epoch may occur. For instance, in the Assam earthquake of 1897, the Goalpara record shows reversals from July to August and from August to September of that year. In the Mino-Owari earthquake of 1891, the Gifu record, as will be seen later, gives seven reversals in thirteen successive days. In the Kwanto earthquake of 1923 (Tokyo record, imperceptible shocks), there were at least eight reversals in ten successive days. In the Tango earthquake of 1927, there were apparently three reversals within about two months. Even in the less destructive earthquakes of New Zealand, there were six reversals in less than four months in the Murchison earthquake of 1929, and four reversals in less than five months in the Hawke's Bay earthquake of 1931. It will be sufficient, as examples, to take the Mino-Owari earthquake of 1891 and the Kwanto earthquake of 1923.

After the Mino-Owari earthquake, the daily numbers during the first thirteen days declined almost uniformly from 310 to 42. Denoting the epochs that coincide with the return movements and occur half-way between them by 1 and ½ respectively, we have the following series of epochs :

½, 1, ½, 1, ½, 1, 1, 1, 1, 1, 1, ½, 1.

The faults of the central district, as determined partly by direct observation, partly by renewed series of levellings, have been mapped by Professor A. Imamura.[1] To the west of the great and well-known fault traced by Koto, there is a triangular block (bounded on the west by another fault) that between 1886 and 1896 bulged upward by from 32·6 to 35·8 inches. Gifu lies close to the western fault. It would seem that the change of epoch was due to the tilting of this crust-block first in one direction and then in the other ; and it is probable that its movement along the western fault was downwards during the first day, with a reversal every day during the first five days.

For the Kwanto earthquake, we may take both classes of shocks, namely, those that were perceptible and imperceptible at Tokyo. The first, on account of their small number, must be grouped in intervals of several days, with the following results :

September 1–6	6–8	8–11	11–13	13–16
½	1	½	½	1

The imperceptible shocks are sufficiently numerous to be taken in separate days and on the fourth day in two halves, and show the following succession of epochs :

½, 1, 1, (½, 1), ½, 1, 1, ½, 1, ½,

showing that there were at least eight reversals in the direction of crust-movement during the first ten days. The studies of Professor

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[1] *Imp. Earthq. Inv. Com. Publ.*, No. 25, 1930, 49–69.

N. Miyabe[1] have revealed the existence of many crust-blocks in the Kwanto plain, and the reversals indicated by these periods were no doubt caused by the varied tilting or one or several of the individual blocks.

After the Tango earthquake of 1927, besides the usual periods, diurnal, lunar, and 42 minutes, there were also similar variations in the mean focal depth of the after-shocks. Of those that occurred from 14th March, 1927, to 31st August, 1928, Mr. N. Nasu has determined the focal depths of 438 shocks.[2] The mean depth was 10·1 miles during 12th to 31st March, 10·2 miles during 2nd to 30th April, 9·1 miles during May, and 9·3 miles during the whole time.

Confining ourselves to these shocks only, they show a marked diurnal period of frequency during the whole interval, with its maximum epoch at 3 a.m. The variation in mean depth is slight, but its maximum occurred at the same time, the depth then being ·28 mile greater than the mean.

The lunar periods are more distinct. The maximum epoch of the 29·6 day period of frequency is undetermined, but the epochs of the 14·8 day period occurred shortly after first and last quarters. For mean depth, the maximum of the 29·6 day period fell shortly after full moon, and the maxima of the 14·8 day period at the same times as those of the frequency, shortly after first and last quarters. At the maximum epochs, the depths were ·9 mile and ·6 mile, respectively, greater than the mean.

The epochs of the 42 minute period have been determined for the three intervals given above. As regards frequency, the maxima during the first two intervals fall about midway between the return movements, in the third interval they coincided nearly with those movements. For mean depth, the maxima during the first two intervals fell nearly midway between the return movements, and during the third coincided closely with them, thus agreeing in point of time with the frequency period. At the maximum epochs, the depths were ·6, 1·0, and 1·2 miles, respectively, greater than the mean.

Thus, until the end of April, all three periods agree in assigning the origin of the after-shocks on the whole to movements of depression. During May the main movement seems to have been one of elevation. After this month the shocks became infrequent, and the movements that gave rise to them can no longer be traced.

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[1] *Earthq. Res. Inst. Bull.*, xi, 1933, 639–692.

[2] *Earthq. Res. Inst. Bull.*, vi, 1929, 245–331; vii, 1929, 133–152.

Differentiation in Basalt Lava, Island Magee, Co. Antrim.

By S. I. Tomkeieff, F.G.S.

Introduction.

THE plateau-lavas of Antrim cover an area of approximately 1,550 square miles—the largest area of Tertiary lavas in the British Isles. Although from the earliest days of geological science these lavas have attracted many observers, very little has been done in the way of petrological study and, curiously enough, the dominant olivine-basalt lava has never been analysed.

Generally speaking the plateau-lavas of Antrim are divided into two sets—the lower and the upper—separated by a thick inter-basaltic bauxito-lateritic zone, marking a long period of subaerial weathering. The lower lavas all over Antrim belong to the same type, namely olivine-basalt (dolerite), a typical representative of the Hebridean Plateau Magma-type. The upper lavas are represented by two contrasted types :—

(*a*) Tholeiitic type (Giant's Causeway type)—a representative of the Tholeiitic Magma-type (non-porphyritic Central Magma-type of Mull).

(*b*) Olivine-basalt (dolerite) type, identical with that of the lower lavas.

The first type (*a*) is restricted to the northern part of Antrim, while the second type (*b*) is found in the south of Antrim, and it is noteworthy that these two areas are separated by a marked tectonic feature—the Highland Border Ridge, stretching from Torr Head to Sperrin Mountains.

Island Magee Basalt Lavas.

In Island Magee, near Larne, the lower lavas are composed of a number of flows averaging 10 feet in thickness and of a total thickness about 200 feet. While the central portion of each flow is made of compact basalt, both the top and the base of the flow consist of highly vesicular zeolitic rock. A fault (NW.-SE.) stretching from Brown's Bay to the Gobbins (Geol. Survey Map of Ireland, Sheet 21, 1883) throws the lavas to the north-east. A constructed cliff-path at the Gobbins enables one to examine a very fine section of the lavas. Along the shore to the south of the Gobbins one can follow the lavas and the underlying Chalk. These are greatly affected by large landslips which are responsible for the vertical position of the lavas and Chalk in certain places. Farther south at Black Head the lavas are again well exposed.

Some of the lavas, especially those forming thick flows, show a distinct change in appearance towards the base. In contrast to the normal black compact basalt, the base is formed by a rock of coarser texture and of a characteristically spotted appearance.

Probably the most accessible example of this can be found in the section of the new road just above the entrance to the Gobbins cliff-path, but it can also be seen among the numerous lava-flows of the Gobbins cliffs and all along the shore as far as Black Head. Similar facies are to be observed among the lavas of Downhill and all along the scarp of plateau-basalts facing Lough Foyle, so that in Island Magee we are not dealing with an isolated phenomenon.

One of the lava-flows from the Gobbins has been selected for detailed study. The thickness of this flow is approximately 15 feet and it presents the usual appearance, namely an upper and a lower vesicular zone and a middle compact zone. The three zones grade into one another.

(1) *Vesicular Olivine-basalt* (*upper zone*). The upper and the lower vesicular zones are identical in composition and structure. Several large blocks from the upper vesicular zone have been crushed and sampled for analysis (Table 1, 1), which shows a high percentage of water, obviously conditioned by the large amount of zeolites in the rock. Measurement of this rock on the Shand stage proved to be impossible, but a planimetric estimation shows that zeolites comprise from 25 to 50 per cent of the rock (volume).

TABLE 1.

ANALYSES OF ISLAND MAGEE BASALT LAVA.

	1	*1a.*	2.	*2a.*	3.	*3a.*
SiO_2 . .	44·15	49·51	46·12	47·80	44·60	47·38
TiO_2 . .	1·35	1·51	1·37	1·42	1·25	1·33
Al_2O_3 . .	15·49	17·38	15·46	16·03	12·15	12·91
Fe_2O_3 . .	7·57	8·48	3·85	3·99	3·41	3·62
FeO . .	2·57	2·88	6·51	6·74	6·57	6·97
MnO . .	0·20	0·22	0·21	0·22	0·15	0·16
MgO . .	6·36	7·13	10·12	10·50	16·84	17·89
CaO . .	9·08	10·19	10·66	11·04	7·80	8·28
Na_2O . .	2·01	2·26	1·48	1·53	0·66	0·70
K_2O . .	0·31	0·35	0·65	0·67	0·62	0·66
P_2O_5 . .	0·08	0·09	0·06	0·06	0·09	0·10
S . .	—	—	tr.	—	—	—
CO_2 . .	—	—	—	—	—	—
H_2O+ .	5·80	—	2·38	—	3·60	—
H_2O- .	4·90	—	1·01	—	2·40	—
	99·87	100·0	99·88	100·0	100·14	100·0
Sp. Gr. .	2·600		2·929		2·842	

1. Vesicular zeolitic basalt. Upper part of lava-flow. The Gobbins, Island Magee; analyst W. H. and F. Herdsman.

1a. Same, recalculated as water-free.

2. Olivine-basalt. Middle part of lava-flow. Same locality; analyst S. I. Tomkeieff.

2a. Same, recalculated as water-free.

3. Chrysophyric basalt. Lower part of lava-flow. Same locality; analyst W. H. and F. Herdsman.

3a. Same, recalculated as water-free.

Zeolites were picked by hand from the crushed material, their purity checked under the microscope, and then separated by means of heavy liquid (Sp. Gr. 2·20) into two portions. These, after washing and drying at room temperature over three months, were examined under the microscope and analysed.

The heavier portion (Sp. Gr. 2·285) is composed mainly of a fibrous zeolite which shows positive and negative elongation in different aggregates, rather high birefringence, and a refractive index varying between 1·51 and 1·53. Extinction is straight or at a small angle. The optical properties and the chemical analysis (Table 2, 1) suggest that the mineral is thomsonite, but the absolute purity of the material is not guaranteed.

The lighter portion (Sp. Gr. 2·160) is entirely composed of granulo-crystalline zeolite, occasionally showing rhombohedral outlines. Under the microscope it shows a weak birefringence and a refractive index of about 1·47. The cleavage is rhombohedral or prismatic. The optical properties and the chemical analysis (Table 2, 2) indicate chabazite, but there is a possibility of admixture of levynite and gmelinite. The last two minerals are recorded as occurring in Island Magee (Dana, *System of Mineralogy*, 6th ed., 594, 595) and I have also found large crystals of gmelinite in lava vesicles along the shore south of the Gobbins.

TABLE 2.

ANALYSES OF ZEOLITES FROM BASALT LAVA.

	1	2.	3.	4.
SiO_2 .	39·90	43·45	43·13	45·23
Al_2O_3 .	29·81	22·37	23·13	24·76
Fe_2O_3 .	0·91	0·12	0·20	0·43
FeO .	—	—	—	0·08
MgO .	tr.	tr.	—	0·83
CaO .	9·91	7·90	8·10	6·76
Na_2O .	5·98	4·48	4·63	6·17
K_2O .	0·16	tr.	0·02	0·82
$H_2O +$.	9·35	15·82	20·79	15·22
$H_2O -$.	4·25	5·78		
	100·27	99·92	100·00	100·00
Sp. Gr. .	2·285	2·160		

1. Thomsonite, in basalt, Island Magee; analyst S. I. Tomkeieff.
2. Chabazite, same locality; analyst S. I. Tomkeieff.
3. Calculated mixture of 10 per cent thomsonite (1) and 90 per cent chabazite (2).
4. Average of twenty-nine previously recorded analyses of zeolites from Co. Antrim.

No mineral other than these two zeolites has been found in the material examined, although some of the colourless isotropic substance occasionally met with could perhaps be referred to analcite. Calcite was particularly marked by its absence, although it is often found together with zeolites in vesicles in other parts of Antrim.

In order of crystallization thomsonite as a rule followed chabazite, but some exceptions were noted.

These two minerals occur in vesicles in approximate proportions of 10 per cent thomsonite and 90 per cent chabazite, so that the mixture of this composition (Table 2, 3) probably corresponds to the zeolitic material infilling the vesicles. Table 2 shows the comparison of this mixture with the calculated average of twenty-nine previously recorded analyses of Antrim zeolites. In spite of the approximate nature of the average, considering the casual collection of zeolites and the inferior analyses of the early investigators, the two analyses (3 and 4, Table 2) are fairly comparable. This, taken together with the geological evidence, points to the fact that the Antrim zeolites mainly belong to the lime-soda-rich varieties, with predominance of lime. Thus the dominant zeolites are : mesolite (antrimolite, harringtonite), chabazite, thomsonite, phillipsite, stilbite, levynite, while natrolite and analcite are comparatively rare.

(2) *Olivine-basalt* (*middle zone*). The middle zone of the flow consists of dark compact olivine-basalt with a hackly fracture. Under the microscope it has a fairly fresh appearance. Olivine phenocrysts (up to 1 mm. in diameter but usually much smaller) are only occasionally idiomorphic, and allotriomorphic plates, often sub-ophitically enclosing feldspar laths, are common. This feature is common in all the olivine-basalt lavas of Antrim. The alteration along the borders is slight. The groundmass is made of slightly chloritized labradorite laths averaging 0·1 mm. in length and a sub-ophitic purplish augite and iron-ore in form of small rods and grains. The mesostasis consists almost entirely of micro-fibrous chlorite. The mode of this rock is given in Table 3 and the chemical analysis in Table 1. It is a typical representative of the Plateau Magma-type of Mull (1).[1]

(3) *Chrysophyric Basalt* (*lower zone*). The basalt of the middle zone gradually passes towards the base into a coarser spotted rock which in turn passes into the comparatively thin lower vesicular zone. Under the microscope the coarse rock shows numerous phenocrysts and glomeroporphyritic aggregates of olivine. The olivine phenocrysts are, as a rule, idiomorphic and each grain has a marked border of iddingsite passing outwards into what is probably a variety of chlorophaeite. The smaller grains of olivine are completely altered. The labradorite laths are much larger than those of the basalt previously described. Albite twinning and continuous zoning are marked. Some feldspars, especially those adjoining the zeolites, are turbid. Purplish-brown augite occurs in the form of ophitic plates. Iron-ore is not abundant and in most part associated with altered olivine. Zeolites are quite conspicuous. Both granular chabazite and fibrous thomsonite occupy ophitic patches and often enclose small feldspar laths surrounded by a very narrow zone of concentrically fibrous mineral. Fibrous chlorite is also present.

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[1] See list of references at end.

The samples measured show two varieties: one richer in olivine and feldspar and poorer in pyroxene (Table 3, 3*a*) and the other poorer in olivine and feldspar and richer in pyroxene (Table 3, 3*b*). The distribution of these two varieties in the rock mass is apparently irregular and the average of the two (Table 3, 3*c*) would probably represent the rock as a whole. The olivine-rich variety is coarser with a well developed ophitic texture, while in the olivine-poor variety the pyroxene is sub-ophitic to granular.

TABLE 3.

MODES (WEIGHT) OF BASALTS, ISLAND MAGEE.
(Nos. 2 and 3 correspond to the analysed specimens, Table 2.)

	2.	3*a*.	3*b*.	3*c*.	4.	5.
Olivine	18·55	42·70	30·75	36·72	22·93	35·35
Feldspar	34·80	33·50	21·10	27·30	31·85	33·25
Pyroxene	32·50	15·90	36·00	25·95	34·92	17·60
Chlorite	9·25	2·35	1·90	2·13	4·35	8·85
Zeolites	—	4·20	7·30	5·75	—	0·85
Iron-ore	4·90	1·35	2·95	2·15	5·95	4·10
	100·00	100·00	100·00	100·00	100·00	100·00
Sp. Gr.	2·929	2·830	2·846	2·838	2·918	2·845
Average size of olivine phenocrysts	mm. 0·35	mm. 0·70	mm. 0·85			
Average size of feldspar laths	0·10	0·30	0·10			

2. Olivine-basalt. Middle part of lava-flow. The Gobbins, Island Magee.
3*a*. Chrysophyric basalt, olivine-rich variety. Lower part of the same flow.
3*b*. Chrysophyric basalt, olivine-poor variety. Same.
3*c*. Average of 3*a* and 3*b*.
4. Olivine-basalt. Middle part of lava-flow. Black Head, Island Magee.
5. Chrysophyric basalt. Lower part of the same flow.

Note.—The figures for olivine also include iddingsite, secondary iron-ore, etc.

The chemical analysis of this rock (Table 1, 3) shows a high percentage of MgO, obviously determined by the high amount of olivine it contains, but this, however, does not allow us to place the rock among the oceanites which, on the whole, are richer in MgO. Its composition is nearer to that of picro-teschenites and kylites, but these rocks are richer in alkalies. The name of picrite-basalt has been applied to similar types of basalt, but it is rather misleading, and the term chrysophyric basalt or, to be more precise, chrysophyric zeolite-basalt, would be more apt.

(*a*) *Olivine.* In order to analyse the olivine, the crushed and washed portion of the rock was fractionated by means of Rohrbach solution. The heavier portion (above 3·23) was entirely composed of fresh green olivine and iron-ore dust. The purity of the material was checked under the microscope and iron-ore was finally extracted by means of a magnet. The determination of refractive index

(12 grains) gave an average $\alpha = 1{\cdot}662$ and $\beta = 1{\cdot}695$. In the microsections the majority of the olivine phenocrysts show a positive sign. The analysis of olivine (Table 4, 1) shows a close analogy to some published analyses of olivine from Tertiary and Quaternary basalts, such as that from Jan Mayen basalt, analysed by Sharizer (Dana, *System of Mineralogy*, 6th ed., anal. 16, 453), and that from Mauna Loa basalt, analysed by Steiger (Daly, *Journ. Geol.*, xix, 1911, 295). On recalculation our analysis approximately corresponds to 85 per cent of forsterite and 15 per cent of fayalite. Assuming that all the olivine shown in the mode (Table 3, 3) is of that composition we shall get an excess of MgO in the analysis. It is clear, then, that the analysed mineral does not correspond to the average olivine in the rock. The borders of iddingsite and other alteration products have apparently been rubbed off during the process of crushing, leaving only solid cores of fresh olivine. These border zones occupy a considerable volume of the whole. For example, the volume of a zone one-tenth of the radius of a sphere is 27·2 per cent of the total, that of one-fifth of the radius 48·7 per cent of the total, etc. In the case in point the rims are in average not less than one-tenth of the radius, and therefore the amount of fresh olivine analysed could not be more than 70 per cent of the total as shown in the mode.

(*b*) *Iddingsite.* The bordering iddingsite is a deep reddish-brown mineral, distinctly pleochroic, biaxial, and with a refractive index higher than the fresh olivine of the centre. The extinction is straight and the optical orientation is the same as that of its parent olivine. As a rule the whole rim is composed of one crystalline individual. The junction with olivine is usually quite sharp, but sometimes a gradual transition is observed, as well as reddening along the cracks of olivine crystals, probably due to incipient iddingsite.

According to Ro s and Shannon (2) the average composition of iddingsite (five analyses) corresponds to the formula: $4H_2O.MgO.Fe_2O_3.3SiO_2$, where MgO may be partly replaced by CaO, and Fe_2O_3 by Al_2O_3. The same authors hold the opinion hat iddingsite is a deuteric mineral formed at the expense of olivine of suitable composition (iron-rich olivine). For the purpose of comparison, an average composition of iddingsite (eight analyses) has been calculated by the present author (Table 4, A).

The iddingsite zone passes into a brownish cryptocrystalline outer zone, which in many cases takes the place of iddingsite and in small olivine grains completely replaces the mineral. Under a high-power objective this brownish material is seen to be composed of minute birefringent granules, with a refractive index lower than that of olivine, immersed in an amorphous groundmass. Ross and Shannon (2) have noted a yellowish cryptocrystalline material associated with iddingsite and suggested that it may represent a transition stage in the alteration of olivine into iddingsite and may be a variety of chloropal.

TABLE 4.

ANALYSES OF MINERALS FROM BASALTS AND DOLERITES FROM CO. ANTRIM.

	1.	A.	2.	B.	3.
SiO_2 .	40·47	38·10	34·30	32·95	42·03
TiO_2 .	—	0·08	abs.	0·62	—
Al_2O_3 .	0·19	2·53	3·74	5·40	3·93
Fe_2O_3 .	—	33·75	19·63	12·37	31·69
FeO .	10·54	0·20	1·52	9·18	0·09
MnO .	tr.	—	0·09	0·33	—
MgO .	48·09	6·87	6·49	4·75	0·53
CaO .	0·29	2·23	1·50	3·05	1·99
Na_2O .	—	—	0·93	1·68	0·12
K_2O .	—	—	1·85	0·36	0·09
$H_2O +$.	0·25	8·67	7·00	5·20	8·50
$H_2O -$.	—	7·57	22·85	23·90	11·30
	99·83	100·00	99·90	99·79	100·27
Sp. Gr. .	3·339		2·071	1·81 ±	

1. Olivine, from chrysophyric basalt. The Gobbins, Island Magee ; analyst S. I. Tomkeieff.

A. Iddingsite, average of eight analyses.

2. Chlorophaeite, from dolerite. Carnmoney Hill, near Belfast ; analyst S. I. Tomkeieff.

B. Chlorophaeite, from dolerite. Ravelig quarry, Dalmahoy ; analyst W. H. Herdsman (R. Campbell and J. W. Lunn, *Min. Mag.*, xx, 1925, 438).

3. Chloropal, from volcanic agglomerate, Carnmoney Hill, near Belfast ; analyst S. I. Tomkeieff.

As the isolation of this material from the chrysophyric basalt proved to be impossible, I propose to compare it with a similar material associated with the dolerite of Carnmoney Hill.

(*c*) *Minerals associated with the Carnmoney Hill Dolerite.* Carnmoney Hill (5 miles north of Belfast) is a neck of volcanic agglomerate pierced by a plug of coarse ophitic dolerite. The dolerite is characterized by remarkably fresh labradorite and pyroxene, but practically devoid of olivine, the place of which is apparently taken by a pitch-like mineral, first noted by Hull (3), analysed and named " hullite " by Hardman (4) and later described by Lacroix (5) and Cole (6).

The mineral occurs in the groundmass and the vesicles. It is black to brownish-black, pitch-like, and with a conchoidal fracture. Under the microscope two varieties can be distinguished : (*a*) micro-fibrous brush-like aggregates, with a straight extinction, lining the walls of cavities, (*b*) isotropic brownish substance usually concentrated in the centre.

Hardman's analysis shows only 13·62 per cent total water, and many doubts have been expressed as to the accuracy of this determination. Heddle suggested that it might represent a desiccated chlorophaeite " either from exposure to a warm atmosphere, or from having been carried in the waistcoat pocket, or dried in the bath previous to analysis ", (7, p. 89). Sollas and McHenry (8) have noted a dark brown resinous mineral similar to " hullite " but with 27·4 per cent of total water, and also have suggested that it is possible that some error crept into Hardman's results. These doubts are entirely confirmed by the new analysis of the mineral from Carnmoney Hill dolerite (Table 4, 2). To procure the pure material the rock was coarsely crushed and fractionated by means of heavy liquids of specific gravity 2·59, 2·37, and 1·90 in succession. The two lightest fractions consisted of pure material. The specific gravity of the analysed sample (pycnometric determination) proved to be 2·071, while the average of several determinations on individual grains is 2·005 (variation from 1·862 to 2·250). The average refractive index is 1·464.

Thus the mineral from Carnmoney Hill is a chlorophaeite and can be easily matched by a recent analysis of this mineral from Dalmahoy Hill dolerite (Table 4, B). The only other specimen called " hullite ", from Kinkell Ness, Fife, is probably a delessite, as actually suggested by Heddle who described it (7, p. 109).

The water in the Carnmoney Hill chlorophaeite was determined with special care. It took ten hours to drive it out at 105°C, and after standing one hour in the open air at room temperature the sample regained 5·5 per cent of the water lost. On heating three hours at 115°C it lost another 2 per cent of water, while the remainder was driven out at red heat.

The chlorophaeite from Carnmoney Hill, however, does not change its colour on exposure. This may be due to the porous nature of the rock in which it is found or the absence of fresh deep exposures.

The chlorophaeitic dolerite of Carnmoney Hill, except for the absence of olivine, resembles normal olivine-dolerites of Antrim, in which olivine is often replaced by iddingsite and chlorophaeitic material. The same can be observed in the Giant's Causeway basalt. This suggests a genetic connection between olivine, iddingsite, and chlorophaeite.

Besides chlorophaeite, another mineral from Carnmoney Hill may deserve description. It was found together with calcite in a cavity in the volcanic agglomerate adjoining the dolerite plug, some few feet from the junction. It is brownish with a dull waxy lustre and starchy fracture. On the assumption that this substance was another variety of chlorophaeite it was analysed. The analysis (Table 4, 3), however, shows that it is chloropal (nontronite). Under the microscope it is seen to be composed of minute birefringent granules, the maximum diameter being 0·01 mm. The refractive index could not be accurately determined, but it is between 1·57 and 1·63. Probably this mineral is a hydrothermal product formed in connection with the intrusion of dolerite. In certain respects this mineral bears a resemblance to the cryptocrystalline material associated with iddingsite in the Island Magee basalt. In the absence of more precise determination one can refer this indefinite material, usually called " ferrite ", either to chlorophaeite or chloropal or both.

Comparison between the average composition of olivine, iddingsite, chlorophaeite, and chloropal can only be made in respect of the major molecular groups, as the oxidation of iron produces great variability of the respective amounts of RO and R_2O_3 oxides. Expressed in molecular proportions ($SiO_2 = 20$) the average composition of these minerals is as follows :

	H_2O.	$RO + R_2O_3$.	SiO_2.
Olivine (theoretical) . .	—	40	20
Iddingsite (eight analyses) .	28	15	20
Chlorophaeite (thirteen analyses)	34	16	20
Chloropal (forty analyses) . .	31	8·5	20

Thus, except a certain variability in water content, Fe-olivine, iddingsite, chlorophaeite, and chloropal form a series of progressive de-basification and hydration.

DIFFERENTIATION.

Comparison of the analyses of the three successive zones of the lava flow (Table 1) already shows the rapid increase of MgO as we proceed downward. Owing to the variable amount of water in these analyses it is impossible to plot them on the usual type of variation diagram but, by recalculating the analyses as water-free, the construction of such a diagram becomes simple (Fig. 1).

The rapid increase in MgO as we proceed from the upper to the lower zone, taken in conjunction with the respective modes (Table 3), indicates the increase in Mg-rich olivine. The same variation is even better shown by the Niggli values of the three analyses : –

	si.	*qz.*	*al.*	*fm.*	*c.*	*alk.*	*mg.*	*k.*
1. Upper .	115	– 7·3	24·0	45·5	25·0	5·5	0·54	0·09
2. Middle .	100	– 16	19·5	51·5	25·0	4·0	0·64	0·23
3. Lower .	89	– 19	14·5	67·0	16·5	2·0	0·75	0·35

Here we have two antipathetic sets of values :—

(1) Increasing downward — fm, mg, k.
(2) Decreasing downward — al, c, alk.

The downward increase of K_2O is rather perplexing, unless we assume that it is associated with chlorophaeite, as in Carnmoney Hill we have a potash-rich chlorophaeite ($K_2O = 1·85$, $Na_2O = 0·93$).

Consideration of the chemical and modal analyses, together with the observed field evidence, leads us to the following conclusions :—

(1) There has been a gravitational sinking of olivine without remelting. The early-formed Mg-rich olivine developed an outer zone of Fe-rich olivine, which, in contact with the residual hydrous magma, was transformed into iddingsite and this, in turn, was transformed into chlorophaeite and chloropal. In this way a discontinuous reaction series (olivine-iddingsite-chlorophaeite) has been produced under the influence of a hydrous iron-enriched residual magma. In a dry melt one would expect a continuous reaction series (forsterite-fayalite) to be produced.

Besides the evidence derived from the chemical and modal analyses two additional observations support the idea of gravitational sinking of olivine. The first observation refers to the perfect idiomorphism of olivine in the lower zone as contrasted with the frequently observed allotriomorphic (sub-ophitic) relation of this mineral to the feldspar in the middle zone. According to Vogt (9), this phenomenon depends on the position of a given melt relative to the boundary line (individualization boundary) between the fields of olivine and feldspar, and apparently in olivine-rich rocks the olivine begins and ends its crystallization before feldspar. The same phenomenon had been observed by Walker (10) in a crinanite-picrite sill in the Shiant Isles. The second observation refers to the striking contrast between the size of olivine phenocrysts and the grain of the groundmass in the chrysophyric basalt (Table 3). This fact has been noted by several observers (11, 12, 13), who attribute it to the effect of sinking olivine.

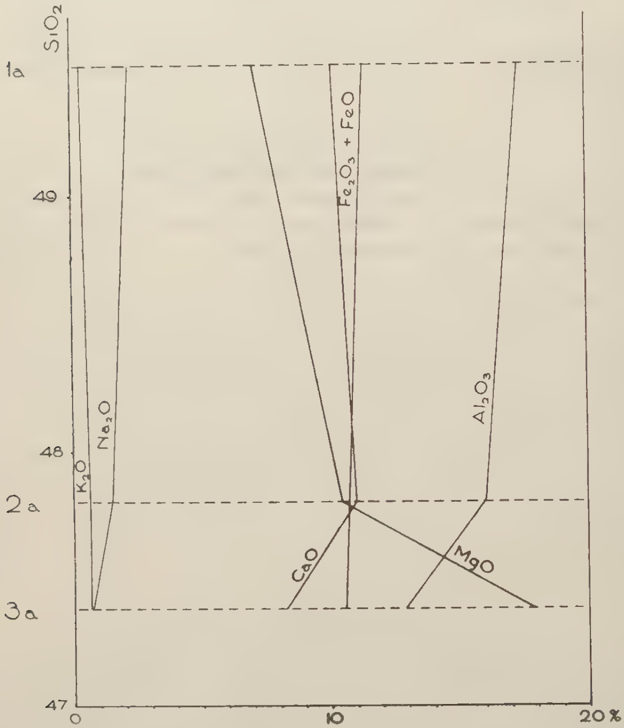

FIG. 1.—Variation diagram of lava flow, Island Magee. 1*a*, 2*a*, and 3*a* are the water-free analyses of the successive zones of the lava flow (see Table 1).

The separation of Mg-olivine implies the enrichment of the residual magma in iron oxides. This is reflected in the trend of the iron oxides curve (Fig. 1). The study of the late differentiates (pegmatoïdes) of basalts by Kennedy (14) points to the same conclusion. Calculation of an average from the eight analyses of olivine-basalt pegmatoïdes given by Kennedy (14, p. 245) shows a relative richness in iron oxides ($Fe_2O_3 = 5{\cdot}14$, $FeO = 5{\cdot}61$, $MgO = 3{\cdot}22$). The Niggli value *mg*, which is a reverse index for iron oxides, is even lower for pegmatoïdes (0·35) than that for the upper zone of Island Magee basalt (0·54). The iron oxide enrichment of the residual magma is probably the main cause of replacement of olivine by iddingsite and chlorophaeite during the final stages of consolidation.

(2) The sinking of olivine was accompanied by a rise of volatiles (mainly water), as shown by the abundance of zeolites in the upper zone of the flow. According to many observers, zeolites cannot be considered to be entirely secondary (post-magmatic) minerals. Harker was one of the first to place zeolites and chlorites in the late magmatic stage of the consolidation of the magma (15, pp. 41–6). Strachan, apparently quite independently, came to the same conclusion in regard to the zeolites in Antrim basalts (16). Fenner (17), McLintock (18), and Holmes (19) are also of the same opinion, although Fenner prefers to regard water as derived from the surrounding sediments.

About one-third of the total volume of the olivine-basalt lavas of Antrim is represented by the vesicular zeolite variety. Taking into consideration the high amount of water vapour emitted during volcanic eruptions, one cannot resist the idea that the water was originally present in the erupted lava, whatever its primary origin.

The upper vesicular zone of Antrim lavas, according to this view, represents the hydrous froth of the erupted basalt magma, while the lower vesicular zone is probably the upper zone rolled over and under the rapidly advancing flow. Protected by these two vesicular envelopes, the interior of the flow could remain liquid sufficiently long to allow gravitational differentiation, helped, no doubt, by the fluid nature of the hydrous magma.

ACKNOWLEDGMENT.

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New Sections showing the Junction of the Cambrian and Pre-Cambrian at Nuneaton.

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In the course of the Leicester meeting of the British Association in 1933, Section C visited the Nuneaton district and saw, amongst other exposures, sections showing the junction of the Cambrian and Pre-Cambrian. Two of these have never been previously described, and the most striking one (that in the north corner of Messrs. Boon's quarry) was only first seen by the writers when on a preliminary tour of the excursion route. Both sections merit description, in view of the light which they throw upon the nature of the unconformable junction of the two systems, and upon the character of the Pre-Cambrian rocks and their relation to the rocks of Charnwood Forest.

SECTION 1.

In the cutting leading to the crushing plant at Messrs. Boon's Windmill Hill Quarry. (Fig. 1).

The Cambrian quartzite (Hartshill Quartzite), a few feet above the base of the series, is a thoroughly cemented grit, with numerous small fragments of Pre-Cambrian detritus; but as it is traced downward cementation decreases and the lowest two feet or so contain much weathered shaly material derived from the underlying Pre-Cambrian (Caldecote Volcanic Series) and are quite soft and incoherent. Pebbles become numerous at the base, while a number of large rounded and intensely weathered boulders can be seen, extending as high as 8 feet above the unconformable junction. These large blocks are solely of the coarse quartz-felspar tuff which is so common a rock in the Caldecote series, whereas the small pebbles comprise a variety of types derived from the underlying Pre-Cambrian.

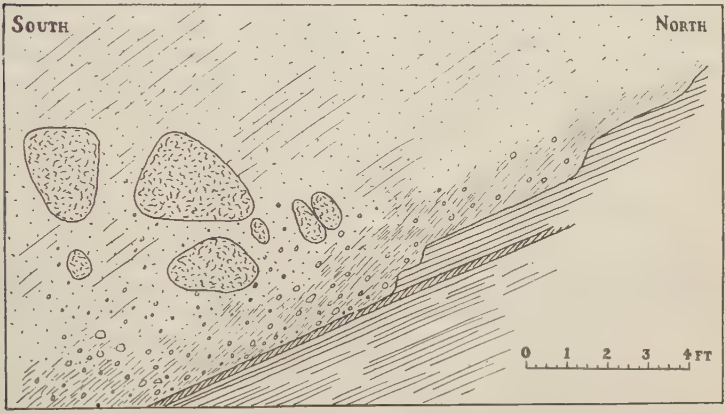

FIG. 1.—A part of the cutting leading to the crushing-plant, Boon's Windmill Hill Quarry (Section 1 of text). Basal Cambrian with large boulders of quartz-felspar tuff, overlying laminated ashes of the Caldecote Series.

The occurrence of boulders at the base of the Cambrian is a feature that has not previously been recorded in the Nuneaton area; but as the second and newer section, described further on in this paper, shows the phenomenon to an even more marked extent, its discussion may be left for the moment.

The actual junction of the Cambrian and Pre-Cambrian is irregular at Section 1. For short distances it follows the bedding planes of the Caldecote series, but is interrupted by steps all rising in one direction, so that the generalized dip of the Cambrian base is steeper than that of the Pre-Cambrian volcanic rocks. It is clear at a glance than an angular unconformity exists between the two systems while dip readings show a slight difference also in strike. The Cambrian, where well-bedded a few feet above the base, dips on an average at 45° in a direction S. 18° W., whereas the Pre-Cambrian has an inclination of only 21° in a direction S. 12° W.

The Caldecote series immediately beneath the large boulders and for some feet to the north, consists of hard, well-jointed, green and purple finely laminated ashes with very regular bedding. A 3 inch band of soft purple shale (possibly also pyroclastic in origin) is the only departure from the first type. In view of the rotted nature of the boulders in the Cambrian base, it is surprising to find the underlying ashes so unaltered a few inches below the unconformity. In the Caldecote rocks no example of the quartz-felspar tuff is seen in contact with the basal Cambrian, but this rock occurs in the cutting a few yards to the north in the same decomposed condition as it is in the derived blocks. The coarse tuff is here apparently faulted against the laminated ashes (the section is rather obscured by talus), and no doubt formed somewhere nearby the early Cambrian land-surface from which the big boulders of Section 1 were derived with very little transport.

SECTION 2.

An extension in the north corner of Messrs. Boon's Windmill Hill Quarry. (Fig. 2).

The sequence in Boon's quarry has been described in the Geological Survey memoir for Coventry [1] and, at the time when that was written, exposed about 160 feet of the Lower Cambrian quartzite (Hartshill Quartzite). The lower 90 feet of this belongs to the basal subdivision of the quartzite (the Park Hill Group) but the contact with the Pre-Cambrian was not visible. Now, as a result of a small extension of the quarry, the contact of the Cambrian and Pre-Cambrian can be seen. The resulting section is one of the most interesting in the Nuneaton district, on account of the light which it throws both on the composition of the sub-Cambrian floor and the nature of the weathering that was affecting it in early Cambrian times, and also on the age of the South Leicestershire plutonic rocks of Markfield, Groby, and other places.

From a descriptive point of view, the exposure may be treated under two headings—(*a*) the basal Cambrian and the nature of its junction with the Pre-Cambrian, and (*b*) the rocks beneath the Cambrian.

(*a*) *The basal Cambrian and the unconformity beneath it.*—Throughout the Nuneaton area, the lowest part of the Cambrian is rich in fragments derived from the Pre-Cambrian Caldecote Volcanic Series, and in the Geological Survey's description of Boon's quarry reference is made to the fact that the lowest 35 feet seen contain this detritus. The quarry extension exposes, in addition, the lowest 10 feet of the quartzite, which is seen to contain massive boulders (see Fig. 2), the largest being about 8 feet long. Bedded against these, and in several cases underlying them to the extent of 3 or 4 feet, is the normal coarse-grained quartzite, together with lenticles of coarse conglomerate containing well-rounded pebbles up to 9 inches. The great boulders are of a size unequalled elsewhere in the district.

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[1] "The Geology of the Country around Coventry": *Mem. Geol. Surv.*, 1923, p. 28.

The actual base of the Cambrian is seen for a distance of about 40 feet. The surface on which it rests dips, in general, at about 30° in a direction S. 30° W., but departs from regularity where the quartzite passes over upstanding rounded bosses of the underlying Pre-Cambrian. It is necessary here to forestall a conclusion in the latter part of this paper and to explain that the rock immediately beneath the quartzite is a coarse plutonic rock similar to that of Markfield in Leicestershire. This markfieldite must have constituted a land surface here in times immediately Pre-Cambrian and have been subjected to extensive weathering under moist conditions. As a result, it has formed great spheroids, several of which can be seen projecting upwards into the Cambrian quartzite (Fig. 2). The advancing Cambrian sea must have encountered many of these pinnacles and, undermining the larger ones, incorporated them in its beach material. Without exception, all the large boulders visible in the section are composed of the markfieldite; their well-rounded character is primarily the result of subaerial weathering

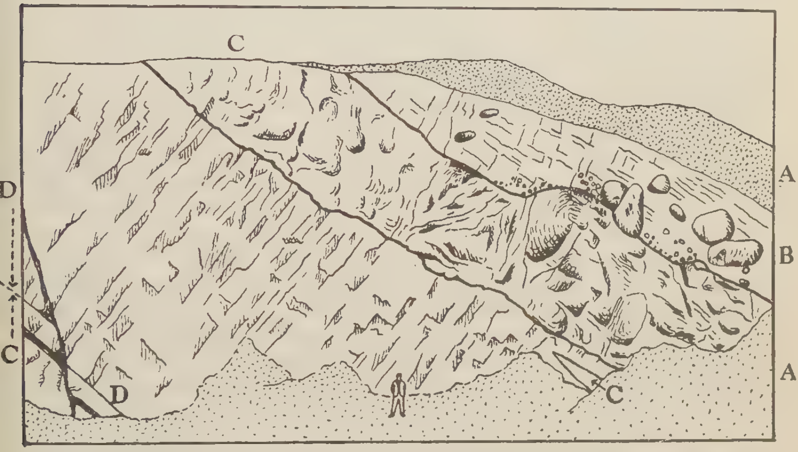

Fig. 2.—Part of the north corner of Boon's Windmill Hill Quarry (Section 2 of text). A, Quarry débris; B, Basal Cambrian quartzite with boulders of markfieldite; C, Markfieldite; D, Microdiorite sill.

dating from the time immediately preceding the Cambrian transgression, and is only secondarily due to Cambrian wave action. In fact it is at first sight difficult to distinguish the boulders from the spheroids that are still in their original positions. It is certainly impossible to believe that the largest blocks have been transported more than a few feet.

The other pebbles which occur in the conglomerate lenticles are small only by comparison with the great markfieldite boulders. Many of them are also of markfieldite, but an equally abundant constituent is the coarse quartz-felspar tuff which forms the boulders of Section 1. A variety of other types occur more sparingly, and a number have been sectioned for examination. They comprise andesites (one epidotized), dolerite, flow-brecciated quartz-plagioclase-porphyry, porphyrites resembling some of the Leicestershire " syenites ", and various fine acid or felspathic ashes.

Many of the pebbles have been sheared by small faults and their displaced portions subsequently firmly cemented by silica.

It is clear that, at the commencement of Cambrian time, the Pre-Cambrian land mass had been eroded to an extent sufficient to expose, not only a wide variety of its volcanic rocks, but also intrusions which, in the case of the markfieldite at least, must have been deep-seated and far below the surface at the period of intrusion.

The base of the Cambrian is also exposed a mile to the north-west of Section 2 in the road to Abell's northern quarry (*Memoir*, pp. 7, 8) but here the pebbles in the basal quartzite are all small and the Pre-Cambrian rocks exposed are chiefly bedded pyroclastics dipping almost exactly at the same angle as the Cambrian. The junction is further obscured by sills intruded along and near to the Cambrian base. Another exposure of the junction used to be visible in the entrance to Boon's quarry, only a few yards south of Section 1, but no certain details of this appear to be extant and the cutting is now completely covered by vegetation. Our knowledge of the sub-Cambrian unconformity in the Nuneaton district has thus hitherto been scanty. The two sections just described, providing evidence in one case of considerable angular discordance and in the other of extensive Pre-Cambrian erosion, throw a new light on the magnitude of the break between the Caldecote Series and the Hartshill Quartzite.

(*b*) *The rocks beneath the Cambrian in Section* 2.—Immediately beneath the Cambrian occurs the spheroidally weathered plutonic rock which has already been referred to as markfieldite (C of Fig. 2). This, in the part of the section illustrated, continues downwards for from 13 to 15 feet (the degree of weathering decreasing with depth) and then gives place to another igneous rock (D of Fig. 2). The junction of the two types is a plane in general parallel to the Cambrian base. The contact is obvious to the eye not so much because of the difference in colour and texture as because of the difference in the fracture planes of the two rocks. Rock C shows the curving planes of its spheroids, whereas D is traversed by a system of straight joints. Near the top of rock D there is a splitting to include a tongue of markfieldite (see Fig. 2).

Rock D has a thickness of 35 feet, its lower limit being parallel to its upper one. Beneath it the markfieldite (C) is again seen for about 3 feet. Then follows a narrow belt of sheared rock, parallel to rock D, but cut and displaced 3 feet by a vertical fault with shatter-belt. Beneath the first shear plane about 25 feet of markfieldite are now visible, with numerous strings of epidotized material in the upper 15 feet.

Rock C. Markfieldite.

In the hand specimen, the rock is moderately coarse and shows a mixture of light green, dark green, and pink constituents in approximately equal areas. The light green material proves, under the microscope, to be subhedral plagioclase, rendered turbid by decomposition, but still recognizable as andesine. A very small quantity of orthoclase felspar is also present as distinct crystals. The dark green areas consist mainly of green chlorite together with some amphibole and, in some cases, calcite. It is difficult to decide how much of the amphibole is original and how much secondary; though some, at least, would appear to be uralite or actinolite replacing, possibly, hornblende, while a pale brown hornblende which occurs sparingly is probably original material which has escaped alteration. A number of the chlorite pseudomorphs, however, show such a marked octahedral shape as to suggest that pyroxene was originally present in considerable amount, though none is now preserved unaltered. We infer, therefore, that the ferromagnesian constituents consisted originally of both hornblende and pyroxene.

Large and abundant crystals of iron ore are a striking feature of the rock slides. In two cut from material above rock D, the opaque mineral contained only small areas of leucoxene, but testing of powdered rock with an electromagnetic separator, with samples of pure magnetite and ilmenite as controls, proved that the unaltered ore is ilmenite in the main. In the rock exposed beneath D the abundant iron ore is now almost wholly represented by leucoxene, except for small inclusions of haematite derived from original magnetite.

The space between the above minerals is filled to a small extent by quartz, but mainly by a fine micrographic intergrowth of quartz and orthoclase, the latter being the major constituent and responsible for the pink areas in the hand specimen. The orthoclase is very turbid through decomposition.

There can be no doubt that rock C belongs to the group of "syenites"—or more strictly, granophyric diorites—which occur in Charnwood Forest at Markfield, Groby, Bradgate, Hammercliffe, Bawdon Castle and Newhurst. Bonney and Hill described these[1] and Lowe[2] has given a more modern account. He separates the rocks of the first three localities (his southern group, 2a) from those of the last three (his northern group, 2b). Group 2a is described as consisting of dominant subhedral andesine, some orthoclase, patches of quartz, areas of green chlorite replacing hornblende (some of which still remains), epidote grains, conspicuous plates of ilmenite, and a prominent interstitial intergrowth of quartz and felspar. The northern type, slightly more basic, shows subhedral plagioclase as the main constituent with probably some orthoclase, associations of chlorite, epidote, and leucoxenized ilmenite, patches of actinolite replacing hornblende and pyroxene (of which some remains), small areas of quartz, and a much smaller amount of the granophyric infilling. To the above descriptions we would add, after examining slides of rock from Markfield and Groby, that the southern type also shows relics of pyroxene and secondary actinolite. We also confirmed by electro-magnetic means that the iron ore, which is only converted to leucoxene to a small extent, is dominantly ilmenite, as stated by Lowe.

The resemblance between the Nuneaton rock and the Leicestershire " syenites " is therefore complete in all important points, such minor differences as do exist being explicable by the greater weathering which has affected the rock at Nuneaton. The fine-textured micrographic material suggests a comparison with Lowe's northern group rather than with his southern one.

Rock D. Epidotized Microdiorite.

This rock agrees in general trend with the numerous intrusions of " diorite " or camptonite which cut the Hartshill Quartzite and Stockingford Shales and, like them, is to be regarded as a sill, though intruded into the markfieldite. Unfortunately, the quarry extension does not allow a simple demonstration of the sill's post-Cambrian age. Its dip is the same as that of the quartzite, but the strike is slightly different. Thus, while on the south-east side of the section the rock is about 14 feet below the quartzite, on the north-west it has approached to within 2 feet; but it cannot be seen either to end against the Cambrian or to cut it.

The rock is moderately coarse-textured, becoming much finer at its contact with the markfieldite. It is holocrystalline, and shows in the hand specimen a mottled pink and black appearance with numerous small patches of bright green epidote. Under the microscope it is seen to be non-porphyritic. The dominant constituents are turbid plagioclase giving the extinction angles of andesine, and chlorite-magnetite pseudomorphs, probably after hornblende, in sub-ophitic relationship to the felspar. Ilmenite and apatite are important accessories. Areas of the rock are replaced by epidote, partly granular and partly in groups of radiating prisms, and by calcite, chiefly in large crystals but also in patches which have a radial appearance, but a strictly parallel crystalline orientation. The rock might be termed an epidotized microdiorite. Dr. F. Raw, who examined this and all the other slides, classified it as belonging to the post-Cambrian diorites before he was aware of its field-relationship, and the variation within these intrusions seems sufficiently great to allow the inclusion of this type among them. The epidotization can be matched by an extensive development of the same effect in the post-Cambrian sill of the Midland Granite Company's quarry, three-quarters of a mile to the south-east. When it is considered that the sill of Section 2 has the same trend as the post-Cambrian diorites, has a system of joints in such contrast to the fractures of the markfieldite as to suggest an intrusion later than the spheroidal weathering, and has apparently furnished no pebbles to the conglomerates at the base of the Cambrian, the post-Cambrian age of the intrusion seems established.

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[1] E. Hill and T. G. Bonney, *Quart. Journ. Geol. Soc.*, xxxiv, 1878, 212.

[2] F. W. Bennett, E. E. Lowe, H. H. Gregory, and F. Jones, " The Geology of Charnwood Forest " : *Proc. Geol. Assoc.*, xxxix, 1928, 282–3.

SHEARING AND EPIDOTIZATION BENEATH THE SILL.

The whole 35 feet of the sill is speckled with epidote-calcite areas, though these become rarer towards the top. The overlying markfieldite is not epidotized. The upper 15 feet of the markfieldite which underlies the sill, however, is also rich in epidote and calcite, but not in the form of scattered patches. Thin threads of the mixed minerals penetrate the rock, the threads being parallel to a gently dipping belt of smashed material occurring 3 feet below the sill (see bottom left-hand corner of Fig. 2). This smash belt may be later than the development of epidote, but it is clear that lines of weakness parallel to this direction have determined the localization of the secondary change. The thickest band of epidote rock is 1½ inches, and composed of parallel strings of granular epidote and calcite. It is itself traversed by small shear-planes with crushing along them, indicating a second movement after the phase of epidotization.

CONCLUSIONS FOLLOWING THE IDENTIFICATION OF MARKFIELDITE IN SECTION 2.

The implications resulting from the identification of rock C, unquestionably of Pre-Cambrian age, as a member of the group of "syenites" of Charnwood Forest, are interesting. The first conclusion is that the dolerite intrusion of the neighbouring Blue Hole (100 yards N.E. of Section 2), which is mapped by the Geological Survey as extending to the base of the Cambrian, covering the site of Section 2 and overlain unconformably by the Cambrian, does not occupy that position. Waller[1] proved that the dolerite was intrusive into the Caldecote Volcanic Series, but its relation to the markfieldite has not been observed. It is possible that in the future the extension of Boon's quarry may work back to the Blue Hole and give evidence of the relation of the two rocks, but until this happens the age of the dolerite, and of the petrologically similar dyke in the road to Abell's quarry, remains unproved and must not necessarily be regarded as Pre-Cambrian.

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[1] T. H. Waller, GEOL. MAG., 1886, p. 324.

The second conclusion which follows from our work is that the intrusions of Markfield type in Charnwood Forest can now indisputably be regarded as Pre-Cambrian. This has often been assumed, but no certain proof has been adduced from Leicestershire itself. If, however, one attempts to proceed from this fact to conclusions concerning the date of the Charnian uplift, contradictions occur between the views of various authors.

The relation of the Nuneaton markfieldite to the Caldecote Series is explained quite simply if the former is an intrusion into the latter, and any other explanation is attended by difficulties. Assuming this simple explanation, it follows that the Caldecote volcanics are the oldest Pre-Cambrian rocks at Nuneaton. Now Watts[1] has argued that the folding and cleavage of the Charnian Series was Pre-Cambrian, on the ground that no cleavage is present in the Cambrian shales of Nuneaton, 18 miles only from Charnwood Forest. But the Caldecote Series, though frequently fine-textured, is also uncleaved, and if Watts's argument is valid it would follow that the Charnian uplift and cleavage are earlier than the Caldecote Series and so earlier than the markfieldite. On the other hand, Jones[2] claims that both the Leicestershire "syenites" and the Charnian rocks have the same dominant joints (in the typical "Charnian" direction and at right angles to this), and that therefore the markfieldite intrusions are earlier than the Charnian movement. Though Watts's conclusion concerning the Pre-Cambrian age of the movement and Jones's views on the relation of the uplift to igneous intrusion are not necessarily contradictory, it does appear on the Nuneaton evidence that one or other of the arguments on which the conclusions are based must be invalid.

We spent some considerable time in examining the joint systems of the Caldecote Series in Section 1, of the markfieldite (C) and of the sill (D) of Section 2, and of the quartzite of Boon's quarry, in the hope that a concordance with Jones's work in Leicestershire would throw light upon the age-relations of the Charnian uplift to the Caldecote series. The results were, however, disappointing from this point of view. The Caldecote series, striking E. 12° S., had only two dominant directions—the master joints grouping around the direction N. 33° E.–S. 33° W., with an equally important counter-set around the direction E. 36° S–W. 36° N. This latter is the typical "Charnian" direction. The quartzite, striking E. 38° S., has dominant joints around N. 59° E.–S. 59° W. (master set) and E. 85° S.–W. 85° N. with second sets around N. 21° E.–S. 21° W. and E. 51° S.–W. 51° N. The joint systems are not at right angles and none corresponds with those of the Caldecote series. But when the markfieldite and the sill D were examined, there was no correspondence whatever with either the quartzite or the Caldecote Series, and it seems quite impossible to use joint directions here as a guide to the date of intrusion. The sill of Section 2 striking E. 12° S. (probably a fortuitous correspondence with the Caldecote Series of Section 1) had dominant joints along the directions N. 8° E.–S. 8° W. and E. 69° S. –W. 69° N., with a third set of gently dipping planes more or less parallel to the sill's top, and striking E. 13° S.–W. 13° N. The markfieldite had no less than five sets of steep joints (N. 12° E., N. 38° E., N. 70° E., E. 12° S., and E. 47° S.) and two sets of gently dipping joints (N. 24° E. and E. 37° S.). We give these results as a matter of record, but we can draw no conclusions from them. It must be admitted that the identification of markfieldite in Section 2 has not led to positive views on the date of the Charnian uplift.

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[1] *Mem. Geol. Surv.* (Sheet 155), Atherstone, 1900, p. 10.

[2] F. W. Bennett, E. E. Lowe, H. H. Gregory, F. Jones, *op. cit.*, pp. 285–295 and references given there.

REVIEWS.

Über Umwandlungserscheinungen an detritischen Staurolith und anderen Mineralien. By C. H. Edelman and D. J. Doeglas. *Tschermaks Min. Pet. Mitth.*, xlv, 1934, 225.

In this short paper the authors give an interesting and useful discussion of processes of alteration observed by them in staurolite, kyanite, garnet, epidote, and sphene in sediments. This alteration takes the form of serrated and fringed edges which are not related to known cleavages, but in some cases to possible faces; e.g. in staurolite to (263). Garnets with serrated edges are often said to be cleaved parallel to (110) but the authors consider that this appearance is due to chemical etching and not to fracture. In conclusion they state that these processes appear to be rare and of little importance in removing minerals from ancient sediments. They consider the greater variety of mineral species in later deposits is really due to greater variety at the sources and not to selective impoverishment of the earlier sediments. This is a point of considerable importance in connection with the oft-noted poverty of heavy mineral species in the Lower Palaeozoic rocks of the British Isles.

R. H. R.

TERTIARY FAUNAS. A Textbook for Oilfield Palaeontologists and Students of Geology. By A. MORLEY DAVIES. Vol. II: The Sequence of Tertiary Faunas. pp. x + 252. London: Murby & Co., 1934. Price 15*s*.

IT is stated that " This volume deals with the succession of Tertiary faunas in all parts of the world. It discusses their distributions and migrations, and their significance in relation both to the correlation of strata and to the former distribution of land and sea. This connected account will supply the student of local faunas with a background against which his detailed palaeontology should acquire a clearer meaning ". The scope of the work thus obviously differs from that of a stratigraphical textbook in that it is mainly concerned with faunas and only to a slight extent with the nature of the deposits in which they are found.

The first two chapters form an introduction to the study of past faunas and deal with (1) the geographical distribution of animals at the present day, both on land and in the sea, and (2) the geological interpretation of fossils. Although these chapters are in suitable proportion to the size of the book many stratigraphists would have welcomed a fuller treatment of the conditions which affect the life and distribution of marine organisms to-day. The author mentions the sporadic occurrence of fossil starfish in " starfish-beds " which has long been a puzzle to geologists. He thinks that it is difficult to believe that starfish communities only came into existence in a sporadic way, and that it is more probable that normally starfish remains undergo complete disintegration, and that only when certain exceptional conditions inhibit the destructive agencies a starfish community may be preserved to form a starfish bed. No suggestion is made as to what those conditions may have been. With regard to the relative stratigraphical value of different groups of fossils in the Tertiary formations the author appears to agree that the Mollusca are of much less importance as dating fossils than the Echinoids and the larger Foraminifera, but he admits the significance of the evolutionary series in the Mollusca of which a few are mentioned. In correlation there is the ever present difficulty of deciding whether the resemblance between the faunas of different areas is due mainly to similarity of age or similarity of facies.

The main part of the work gives in 175 pages a summary of the characters and relationships of the Tertiary faunas in all parts of the world. Only those who have some special knowledge of the subject will be able to realize the immensity of the task of selecting and summarizing from a mass of detail the essential and fundamental points. The student of geology will be able to appreciate more fully this work when Vol. I, dealing with Systematic Palaeontology, is published, since many fossils are mentioned with which he will not be acquainted, and others, although known, are sometimes obscured under unfamiliar names. The value of the bibliographies given at the end of each chapter is increased by the references to the individual works in the text by numbers so that further information can be easily obtained.

Although reconstructious of the geography of some periods of the Tertiary have been attempted by various authors, one doubts, after reading this work, whether there will ever be sufficient evidence available to warrant zoogeographical maps of the past comparable with the one for the present day which forms the frontispiece.

LEITFOSSILIEN. Lieferung 7: Wirbellose des Jura. Von E. DACQUÉ. Part I, 1933, pp. 1–272, pls. 1–24; Part II, 1934, pp. 273–582, pls. 25–48. Berlin: Gebr. Borntraeger.

NOW that both parts of this work have appeared, it may be useful to give some account of their contents, for the benefit of any museum curators or fossil collectors who may be contemplating the expenditure of 120·80 marks (approximately £10) on the two paper-covered parts, each slightly exceeding in size but not in thickness a single quarterly number of the *Journal of the Geological Society.*

The purpose of the work is summarized in the subtitle of the Leitfossilien series: "A handbook to help in the identification of fossils during geological work among collections or in the field," and is amplified by the distinguished author of the present instalment in his Introduction. He explains that it is a compilation, almost entirely uncritical, and that the reader most in view is the non-specialist with imperfect access to palaeontological literature. At the outset it may be doubted whether this class of reader is best served by an enormous mass of unsifted matter, for he is just the class who cannot check statements and run down references for himself and therefore he needs his information well-digested and accurate.

Part I contains first of all six pages on "Guide-fossils and Zones". This is written from what may be described as a die-hard point of view, and is strangely dry and out of date. Its inaccuracies of statement result mainly from the failure to take into account any but German literature. The old myth that Oppel originated the conception of the zone is repeated, whereas the zone in reality appeared first in the writings of d'Orbigny and Hébert in France; the opening sentence states that the word zone has never been defined, whereas an official definition was enunciated by the International Geological Congress in 1883 and has repeatedly appeared in British textbooks such as Marr's *Principles of Stratigraphical Geology* (1898); Buckman's terms biozone and hemera are discussed, but both are misrepresented, and it is not mentioned that the biozone in Buckman's sense is synonymous with and antedated by Shaler Williams's term biochron.

There follow five pages on the making, naming, and identification of species and genera. In tone this is still more reactionary; but it contains a great deal of sound sense and a justifiable diatribe against the irresponsible setting up of genera without adequate diagnosis, merely on the strength of a figure of a single specimen. Professor Dacqué may rest assured, however, that by no means all British palaeontologists are under the "hypnotic influence" of Buckman's "unglückselige Beispiel".

The main portion of the book, occupying the bulk of both parts, consists in an enumeration of genera, with brief diagnoses. The compilation of this material must represent an enormous amount of uninteresting work, and it will doubtless be often consulted for reference. Nevertheless, it is obvious that the scope is too great for the result to be exhaustive or reliable, and the sections dealing with the various phyla by no means fill the place of an up-to-date edition of the older manuals, such as Fischer's *Manuel de Conchyliologie* for the mollusca. In spite of the disclaimer in the Introduction that the compilation is uncritical, much critical matter has crept in, and it is often impossible to tell whether an opinion is that of the author, or the founder of the genus, or a subsequent reviser (e.g. in items such as "*Gyroidina* d'Orb., 1826. Mit voriger wohl identisch?"). Often the treatment is so uncritical as to be exasperating.[1] Sometimes it evinces a mere hasty scanning of original sources without even reading of them. No man can speak with authority on all the invertebrates of the Jurassic, and so the present reviewer must limit his remarks to the group with which he is best acquainted —the Lamellibranchs—and this must serve as a specimen for the book as a whole.

The section on Lamellibranchs is marred by the persistent disregard for priority and the frequency of misprints and misstatements. Where two synonyms exist, the later is persistently listed first, with the earlier and only valid name in brackets; all the suppressed synonyms which systematists for decades have been trying to forget are here paraded once again with flying colours—*Leda*, *Macrodon*, *Avicula*, etc. All too often synonyms, which have been shown by reviser after reviser, and even by the original author himself, to be invalid or redundant, are listed as separate genera, and sometimes they are even furnished with separate diagnoses. For example *Pachytypus* Mun. Chal. (1887) is given a longer diagnosis than *Prorokia* Boehm (1883), with which it has long been shown to be perfectly synonymous; *Lucina* and *Phacoides* are treated similarly; also *Ceromya* and *Ceratomya*; *Entolium* and *Syncyclonema*; *Uromya* Rollier, *Eurychasma* Cossmann, and *Goniomeris* Choffat. Both Cossmann and Rollier published retractions of their names in favour of *Goniomeris*, with which their genera are absolutely identical.

Some curiosities are the following:—*Corburella* Lycett, shown five years ago to be identical with *Tancredia* Lycett, is placed sixteen pages away from it, separated by several families; *Corbicellopsis* Cox, which was coined as a *nom. nov.* for *Corbicella* Morris and Lycett, is listed as a separate genus with separate definition, and is not even placed next to its synonym; *Clathrolima* Cossmann, which was soon after its creation (1907) disinherited by its maker and acknowledged to be a synonym of *Pseudomonotis*, is listed in the Limidae; *Eopecten* " Douville 1827 " (!) is listed on page 212 under the Pectinidae as a synonym of *Velopecten*, while on page 213 it reappears as a separate genus under the Spondylidae, attributed to Douvillé, 1897. *Syncyclonema* shares with it the distinction of being alleged to be both a Pectinid and a Spondylid. Sometimes the same name, with slight variations in the appended description and information, appears twice in the same family: *Plesiopecten* even faces its image as in a mirror across the page (pp. 210, 211).

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[1] This applies especially to the listing and separate characterization of dozens of synonyms, e.g. all the abortive names coined by various authors for groups of oysters (pp. 215–17) and the scores of Buckman's names for brachiopods and ammonites, largely with the wrong types.

To continue in this vein would be wearisome. But before concluding one general criticism must be made, concerning the unfortunate system followed throughout of indiscriminately citing a " typus " for each genus, which is sometimes the real type but more often is not. It is explained in very small print on page 20 that the word typus is not intended to mean what it does. But since its meaning is very definite, and of vital importance to the class of people whom the book is designed to help, why use it when only " example " is meant?

Part II concludes with lists of faunal assemblages recorded by different authors from the various formations and localities of the European Jurassic (these cover 97 pages); a list of cephalopod species (22 pages); analyses of vertical distribution of genera; and finally stratigraphical tables and bibliography. To criticize these would occupy too much space for the task to be even attempted.

There are 48 plates, bringing together figures culled from previous works and therefore of very varying accuracy and of all degrees of magnification and reduction (not stated). We may recognize some questionable synthetographs from the earlier authors, and the mixture of drawings of all styles and in all mediums with photographs is not artistically pleasing: but on the whole the collection will be useful if consulted with discrimination. With the whole wealth of the Jurassic faunas of the world to choose from and compress into 48 plates it is puzzling why some species should be figured twice: e.g., *Isocardia cordata* Buckman (plates 9, 21), and *Arcomytilus pectinatus* (Sow.) (plates 34, 35) (misspelt " *Acromytilus* " in both places and misnamed *subpectinatus* d'Orb.): still more why pictures of *Rhamphorhynchus* and a fish should be included.

Other publications received:—

GRUNDZÜGE DER GEOLOGIE UND LAGERSTÄTTENKUNDE CHILES. By J. BRÜGGEN. pp. vii + 362. Published by Max Weg, Leipzig, 1934. Price Mk. 30.

DUST. By S. C. BLACKTIN, M.Sc., Ph.D. pp. xi + 296. Published by Chapman and Hall, London, 1934. Price 18*s*.

THE MONASTIC REMAINS OF NORFOLK AND SUFFOLK. By C. J. W. MESSENT. Norwich : H. W. HUNT, 1934. Price 7*s.* 6*d.*

SOME years ago we reviewed an earlier book by the same author on old buildings in Norfolk because it contained some remarkably good descriptions of the various building-materials of the county. In the present work there is no geology, but it is of great interest in other ways and there are a number of charming sketches as illustrations, many of which are wisely chosen from the less well-known monastic remains of the district. In Suffolk there were about 100 monastic buildings and in Norfolk 180, the little town of Thetford alone having no less than thirteen entries in the list.

CORRESPONDENCE.

QUATERNARY CHANGES OF OCEAN LEVEL.

SIR,—Three articles by Cosmo Johns have appeared this year in your magazine. I did not pay much attention to the first (LXXI, p. 66) for three reasons. (1) It seemed to be an extension of W. B. Wright's hypothesis for Scandinavia, namely that the land recovered from isostatic depression as the ice melted and sometimes the sea rose faster than the land and formed the Yoldia and Tapes beaches. This hypothesis according to Wright includes a quicker recovery in the peripheral regions from isostatic depression (this is to explain the earlier recovery at Vendyssel and Uddevalla). The Ancylus depression, however, was later in the north of the Gulf of Bothnia—well inside the peripheral regions—than in the south, so that Wright's hypothesis must be recast before being employed, much less extended. (2) If there was a general lowering of ocean level during the Quaternary at what times did the level rise to form the Quaternary beaches in North Spain at + 195, 150, 65, and 40 metres not to mention other sites ? (3) An early lapse from logic. Mr. Johns says in effect (p. 67, 1st paragraph) " It could have been *a* or *b*. If it was *a*, I should not be able to prove what I want to prove, therefore it was *b*."

A fourth reason is now added by the recent discovery that the 100 ft. beach is not of the same age on both sides of Scotland—a fact which, I hope, finally explodes the theory that the raised beaches were formed as land ice melted into the ocean.

It would take too much space to go through the papers step by step, especially since Mr. Johns takes us through the domains of geophysics, glaciology, meteorology, and more with bewildering rapidity. Perhaps I might pick out one or two points here and there.

(*a*) The 100 ft. terrace is much earlier at Swanscombe than in the north : Acheulean implements (? pre-Riss) against Yoldia times (? Buhl). I might also point out that the lower Thames ha been twice or three times up to the 100 ft. level or near, i.e. the 100 and 85 ft. rock ledges, covered with gravel of Acheulean date, and dirty sand at 100–110 feet after Clacton-Levallois times—Burkitt has proposed ponding of the North Sea to account for the latter.

(*b*) In regard to the second paper (p. 176), the coral island problem is a ticklish one for anyone not personally acquainted with the region to tackle. There is an impartial discussion by Steers (*The Unstable Earth*, 1932) and the painstaking work of Chubb recently published (GEOLOGICAL MAGAZINE, LXXI, 189). If for the reasons given above anything to do with a 1,000 m. depression of ocean level is struck out as impossible, nothing much original is left.

(*c*) The third paper (p. 408) is a combination and amplification of the first two, and the geomorphology extremely speculative.

I must protest against Mr. Johns's description of his curve as a "Raised beach" curve. The only beaches he seems to know of are the 140,100 (these are grouped together. Why ?) and 25 ft. beaches. Fig. 2 loses interest when it is known that the so-called "Yoldia sea submergence" did not occur contemporaneously up the east coast of Britain.

However, mere criticism is tedious, and I am glad that there are points on which one can agree with Mr. Johns's findings. One is that the major glaciation of Scotland can be placed in the second half of Penck's Mindel-Riss interval, another that there has been subsidence (though I do not agree to recovery) in the north Pacific.

Might I suggest that Mr. Johns is attacking a very interesting problem in the wrong way, namely by forming a hypothesis and selecting facts to fit it ? Surely the scientific method is to discover first what were the earth movements (wide variations in ocean level can no longer be entertained), taking as a starting-point the raised beaches and river terraces round Europe, second, what caused them ?

R. G. LEWIS.

BLOCK FAULTING IN THE WESTERN RIFT OF CENTRAL AFRICA.

SIR,—In a letter published in the June issue of the GEOLOGICAL MAGAZINE, Dr. E. O. Teale recorded observations by himself and Mr. G. M. Stockley to show that compression phenomena in the rocks along the margins of the Rift in Tanganyika Territory are very ancient and long antedate the present scarps, and that the Rift fractures are everywhere best interpreted as associated with block movements. Mr. Stockley refers particularly to pre-Rift overthrusting in the Livingstone Mountains, and to block-faulting there and in the Ruhuhu trough ; both these areas lie on the eastern side of Lake Nyasa.

The object of this note is to record that the observations of the Nyasaland Geological Survey in and west of the Nyasan trough entirely confirm those of the Tanganyika Geological Survey on the eastern side. These observations may be summarized as follows :—

1. The Mafingi (Muva-Ankole) sediments north-west of Lake Nyasa show ample evidence of compression, and in the northern part of the Mafingi Mountains a magnificent overfold can be observed, in which the direction of movement is approximately parallel with the general direction of the neighbouring part of the Rift. But these movements were definitely pre-Karroo.

2. North-west of Lake Nyasa Karroo sediments lie west of, on the margin of, and within, the Rift ; these sediments have been subject to early post-Karroo faulting and to Rift faulting, but in no case, except locally near the major post-Karroo faults, has any evidence of compression been observed, whereas there is ample evidence of block faulting. Farther south, in the Lake Chilwa region, pre-Karroo (? Waterberg) sediments lie undisturbed, apart from vertical movements, on the floor of the Rift.

3. North-west of Lake Nyasa, early Cretaceous, Tertiary, and Quaternary sediments also lie along the margin of, and within, the Rift ; no evidence of compression has been observed, but all have been subject to block-faulting, and the older beds have been repeatedly tilted in the one direction, towards the deepest part of the Rift ; this hinge-faulting may be observed in parallel subsidiary rifts.

4. Where no sediments have been preserved, the crystalline rocks show step faults which vary from narrow shelves along the main walls to broad shallow steps that extend far out on to the floor of the Rift.

F. Dixey,
Director.

Geological Survey,
Zomba,
Nyasaland.
14th September, 1934.

UNIVERSITY OF LONDON.

A course of three lectures on " Problems of the Archaean and Iron Ore Formations of Middle Sweden " will be given by Professor P. D. Quensel (Professor of Mineralogy and Petrography in the University of Stockholm) at The Imperial College—Royal School of Mines (Prince Consort Road, South Kensington, S.W. 7), on 19th, 20th, and 22nd November, at 5.30 p.m. At the first lecture the Chair will be taken by Dr. H. H. Thomas, M.A., Sc.D., F.R.S., F.G.S. Admission Free, without Ticket.